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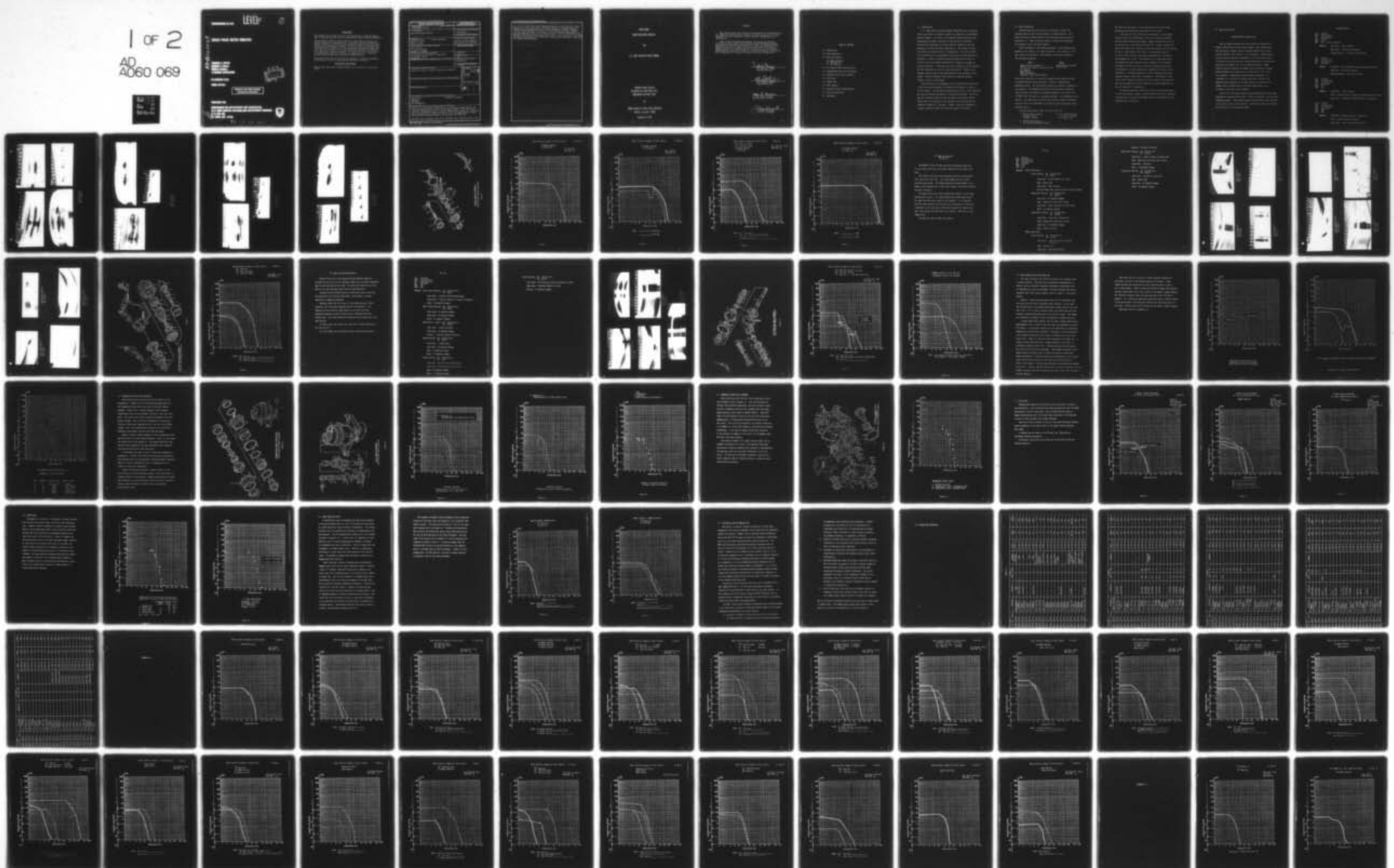

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SHOCK PULSE METER ANALYSIS

[illegible] C. MAYER
[illegible] F. COVILL
[illegible] A. GEORGE
J. [illegible] HARRINGTON

15 OCTOBER 1974

FINAL REPORT

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PREPARED FOR

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Drive Components
Diagnostic Equipment

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report contains Shock Pulse data on the tailrotor hanger bearing, the forty-two degree gearbox, and the ninety degree gearbox. Also this report contains a preliminary study of using the shock pulse technique on the OH-58A and on determining the condition of gears in the 42 degree gearbox. Shock pulse data was collected using the off-the-shelf SKF, MEPA-10A.

The Shock Pulse technique works on the principle that a descrete fault, such

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) as a pit or a spall, will cause repetitive impacts of short duration. These impacts will cause shock waves to propagate through the bearing structure causing a pulse displacement input to an accelerometer, suitably, attached to the bearing structure. The output of the accelerometer passes through a high gain amplifier tuned at the resonant frequency of the accelerometer (this amplifier then acts as a sharp band-pose filter). After the signal is processed the output is displayed on a counter which provides the frequency of peaks above any desired peak amplitudes.

FINAL REPORT

SHOCK PULSE METER ANALYSIS

FOR

U.S. ARMY AVIATION SYSTEMS COMMAND

PREPARED UNDER CONTRACT

DO DAAJ01-72-A-0027-0002 (P6C)

BOA DAAJ01-72-A-0027 (P6C)

BY

PARKS COLLEGE OF SAINT LOUIS UNIVERSITY

CAHOKIA, ILLINOIS 62206

OCTOBER 15, 1974

FOREWARD

This report presents the results of the analysis of the SKF Industries, Inc. MEPA-10A Shock Pulse Meter conducted by Parks College of Saint Louis University with SKF Industries of King of Prussia, Pennsylvania, as a subcontractor.

Parks College gratefully acknowledges the support and assistance of the United States Army Aviation Systems Command (USAAVSCOM) Research, Development and Engineering Directorate, St. Louis, MO; USAAVSCOM Flight Operations Division, St. Louis, MO; United States Army 281st Aviation Company, Cahokia, IL; Hawthorn Aviation, Fort Rucker, AL; United States Army Flight Test Board, Fort Rucker, AL; Garrett Corporation, Torrance, CA; and the Department of Research, Ohio State University, Columbus, OH.

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TABLE OF CONTENTS

1.0 Introduction

2.0 Field Evaluation

2.1 Tear Down Analysis

a) Hanger Bearings
b) 42° Gear Box
c) 90° Gear Box

2.2 Ft. Rucker AIDAPS Helicopter Data

2.3 Transmission Shock Pulse Envelopes

2.4 Generator Offset Quill Assembly

2.5 OH-58 Data

2.6 Flight Data

3.0 Gear Analysis

4.0 Conclusions and Recommendations

5.0 Table and Appendixes

6.0 References

1.0 INTRODUCTION

U. S. Army Aviation Systems Command (USAAVSCOM) has a continuing effort in the area of automatic inspection, diagnostic, and prognostic systems (AIDAPS). As a part of this program, Parks College has been conducting an intensive evaluation of the shock pulse technique. Previous work (references 1-3) have shown the technique to be most promising in certain helicopter applications. This report concerns itself with two separate areas of investigation. The first of these is a continuation of the preliminary work carried out and reported in reference 2. That is, extensive shock pulse data was collected on the tail rotor drive hanger bearings and 42^{o} gearbox to broaden the previous data base. In addition, data was collected on the 90^{o} gearbox, and the transmission of the UH-1 series helicopter. Finally a preliminary study was made on the applicability of the technique to the OH-58A. Selected components were removed for teardown analysis. Chapter 2 reports on this phase.

The second area of investigation was to establish the feasibility of the shock pulse technique to determine the condition of gears in the 42^{o} gearbox. The College subcontracted this effort to SKF Industries who were the original developers of the shock pulse meter. The tests and test conditions were monitored throughout the six-month effort. Faulty gears were implanted in the gearboxes by the College and the signatures compared to a baseline. Chapter 3 along with Appendix 3.1 a report submitted by SKF, discusses this phase of the effort.

2.0 FIELD EVALUATION

The data upon which this section of the report is based was obtained using the shock pulse technique of bearing analysis. Previous work done by Parks College in the shock pulse area is given in References 1-3. These references explain in detail the methodology and equipment used in the pulse analysis.

Data is presented on 106 bearing assemblies. The assemblies were analyzed on two types of U.S. Army helicopters: UH-1 series, H, D, M, and C models and the OH-58. Shock emission curves were obtained on the following assemblies:

UH-1	OH-58
Hanger bearing assemblies	Hanger Bearing assembly
42° Gear Box (input and output quills)	90° Gear Box
90° Gear Box	
Mast Bearing	
Input Drive Quill	
Generator Offset Quill Assembly	

Shock pulse signatures of the various assemblies were taken utilizing a standard MEPA-10A Shock Pulse Meter. Table 2.1 summarized all assemblies tested. The shock emission curves are included in Appendix 2.1 for reference. The assemblies which had shock emissions exceeding a normal envelope were removed for teardown analysis in the case of the 42° gear boxes, 90° gear box, and hanger bearings. No transmissions were removed. The conditions of all tests were kept as constant as possible with all tests run at 6600 RPM N_2 and neutral anti-torque pedal unless otherwise noted.

The helicopters used in data collection were from:

1) 281st Aviation Company
   Bi-State Airport
   Cahokia, Illinois

2) AVSCOM Flight Section
   St. Louis International Airport

3) U.S. Army Test Board
   A.I.D.A.P.S. Program
   Ft. Rucker, Ala.

All tests were performed on a non-interference basis with normal maintenance and operational scheduling of the aircraft.

A description, both narrative and photographic, of the damage found at tear down is presented, as well as a correlation between the shock pulse signature and damage. Damage clarification, as well as descriptions of the assemblies tested at Ft. Rucker, Alabama, are taken from implant part inspection sheets made available to the College by the U.S. Army Aviation Test Board. All components tested at Ft. Rucker which were not specifically implanted with a bearing of known damage were "clean". The reference to a "clean" part infers the assembly had been inspected and all elements of the component are damage free and in as good a condition as physically possible. The advantage of securing shock pulse signatures from these "clean" components is in making comparisons to those assembled with either implanted damage, normal wear or degradation. The premise is that these "clean" elements represent the lowest possible shock emissions and thus the magnitude of shock emissions from other assemblies can give an indication of degradation.

All bearing assemblies which were tested on aircraft belonging to the 281st Aviation Company or AVSCOM Flight Section were components of operational helicopters and damage found was not apparent prior to obtaining shock pulse data.

2.1 TEAR DOWN ANALYSIS

HANGER BEARING TEARDOWN DATA

The four hanger bearings which were removed for analysis all yielded teardown data clearly showing damage. When compared with Bell Helicopter's damage condition category definitions, we would consider between C and D defects on all assemblies. Hanger bearing A20-31435 had the heaviest concentration of corrosion and pitting on the outer race as well as the rolling elements and its shock pulse data shows the highest level of the assemblies tested. Hanger bearing A20-44891 exhibited the highest rate monitored on a hanger bearing assembly and coupled with its shock level of 700, it fit in a category of damage which became evident at teardown. No statements as to the time to complete functional failure of the hanger bearing assemblies can be made; however, we feel that the damage found at teardown would contribute significantly to a decrease in efficiency of the assembly.

Each of the four hanger bearings removed exceeded the normal range signifying a bearing without defect. Refer to reference 2 for the coded normalizing graph. Since hanger bearing A20-44891 had a level which fell in the caution area, it was removed to correlate its tear down evidence with its plot on the normalizing graph.

HANGER BEARINGS

A/C: 63-8784
FSN: 1615-832-8951
PN: 204-040-600-9
SN: A20-36705
TSN: 1166
TSO: 646 (1 prior overhaul)

REMARKS: Inner Race: Mild Corrosion

Outer Race: Pitting and Corrosion

Rolling Elements: Corrosion, Mild Pitting

A/C: 65-9519
FSN: 1615-832-8951
PN: 204-040-600-9
SN: A20-44891

REMARKS: Outer Race: Metal Fatigue, Pitting, Flaking Corrosion

Inner Race: Corrosion, Pitting

Rolling Elements: Corrosion, Pitting

A/C: 69-15949
FSN: 1615-832-8951
PN: 204-040-600-9
SN: A20-55389
TSN: 943
TSO: 500

REMARKS: Inner Race: Light Corrosion

Balls: Light Corrosion, Evidence of Skidding, Some Pitting

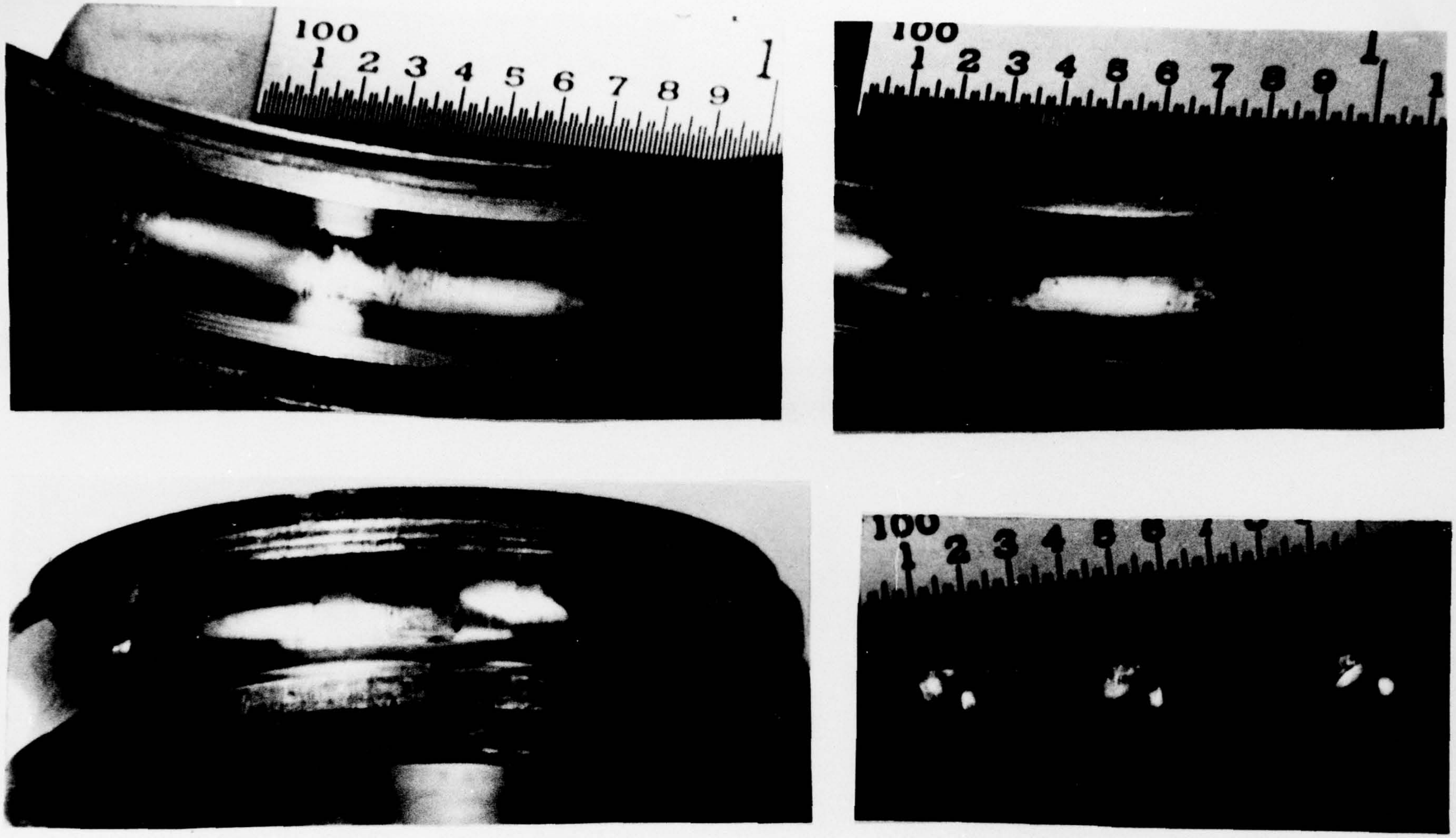
Outer Race: Corrosion, Pitting, Evidence of Skidding

A/C: 63-8784
FSN: 1615-832-8951
PN: 204-040-600-9
SN: A20-31435
TSN: UNK
TSO: UNK

REMARKS: Inner Race: Medium Corrosion, 1 Large Pit

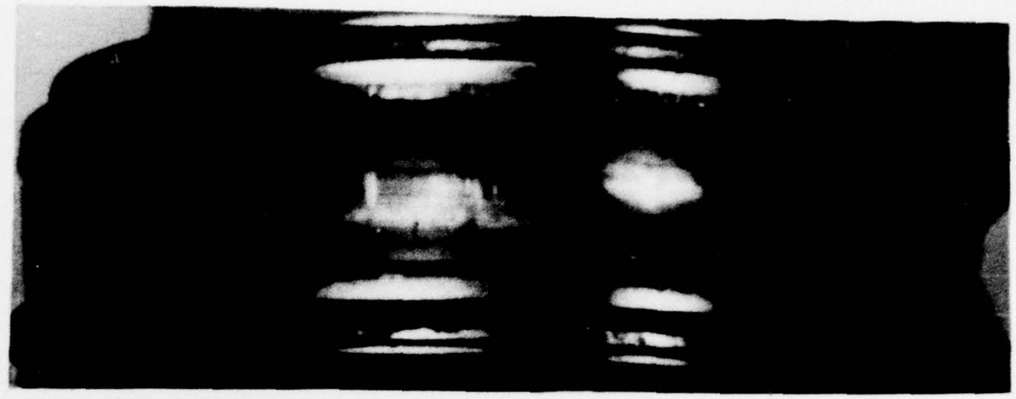
Balls: Light to Medium Corrosion

Outer Race: Heavy Corrosion and Pitting

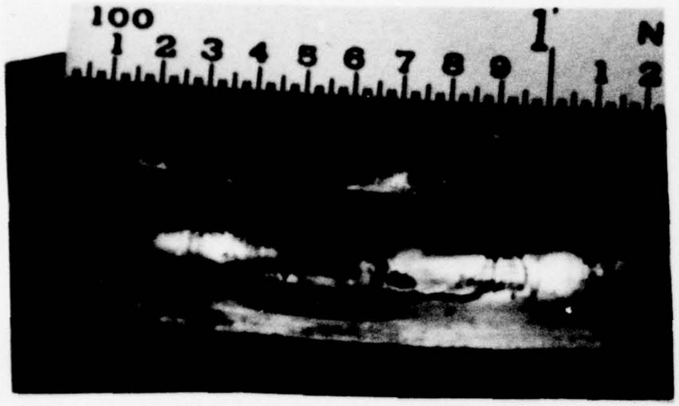


Hanger Bearing
S/N A20-36705
A/C 63-8784

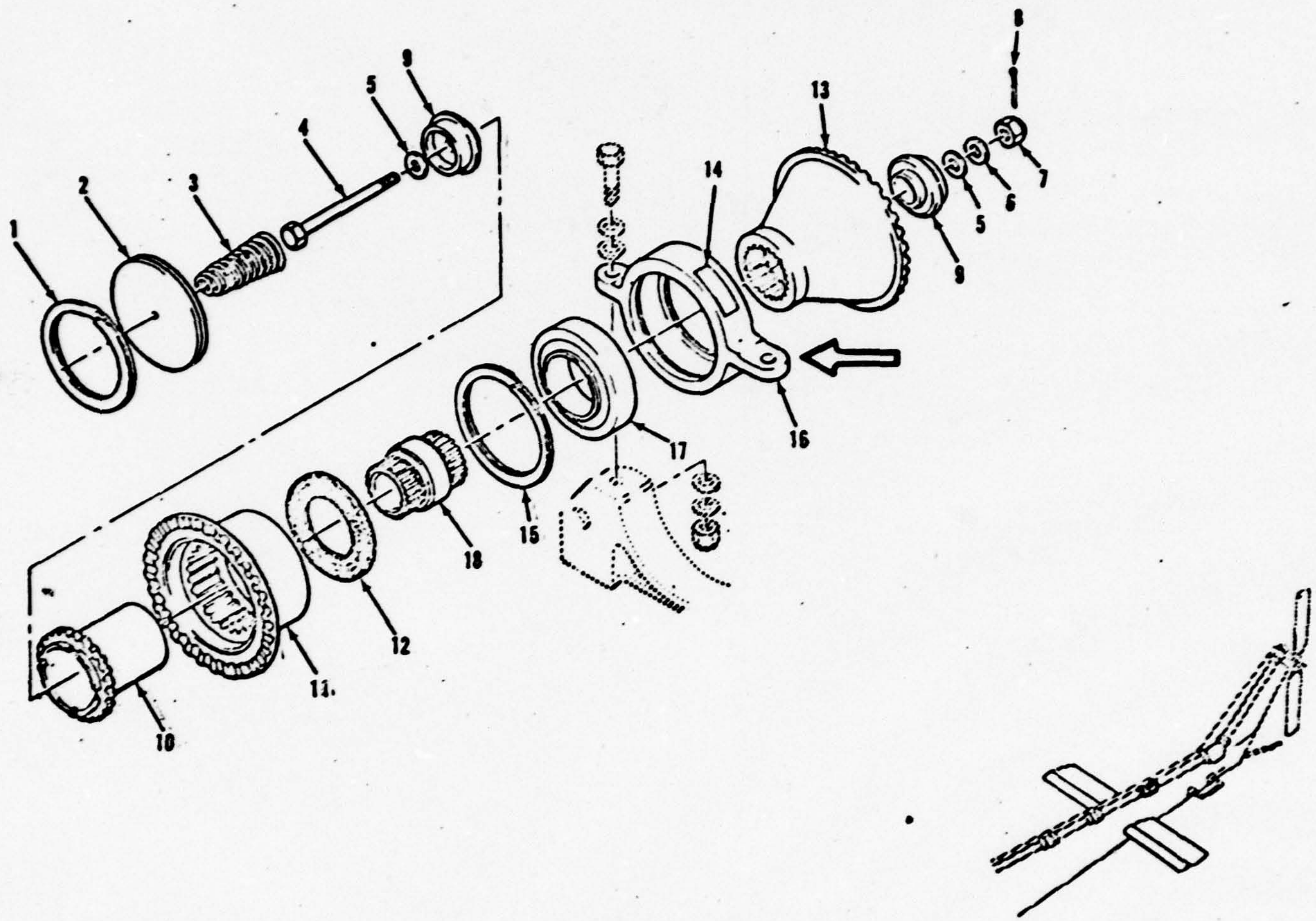
Hanger Bearing
P/N A20-44891
A/C 65-9519



Hanger Bearing
P/N A20-55389
A/C 69-15949



Hanger Bearing
S/N A20-31435
A/C 63-8784



HANGER BEARING ASSEMBLY

ARROW DENOTES SENSOR LOCATION

Figure 1

281st Aviation Company Bi State Airport 23 Sept 74

#1 Hanger Bearing
SN A20-55389

A/C 69-15949
6600 RPM N_2

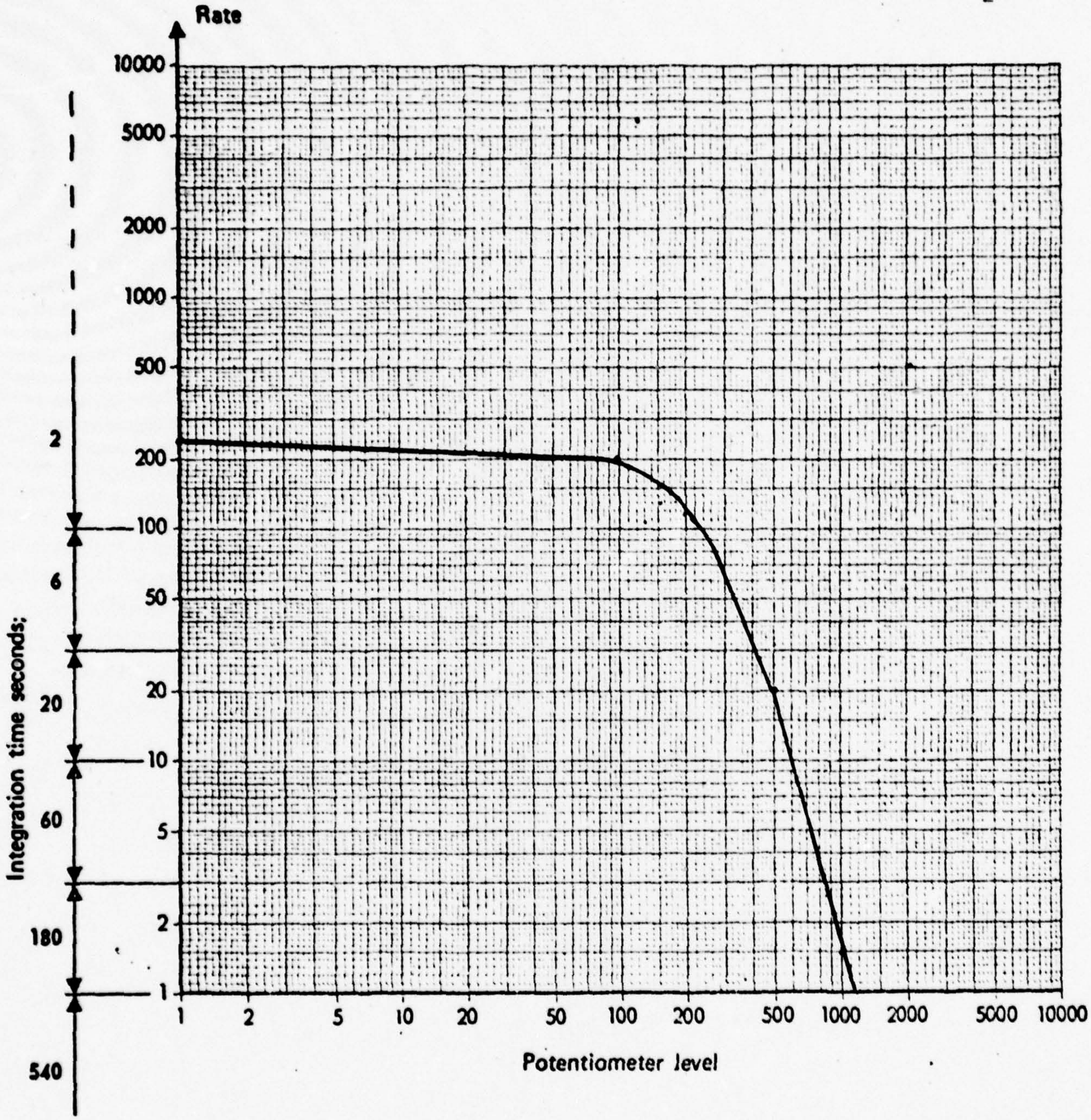


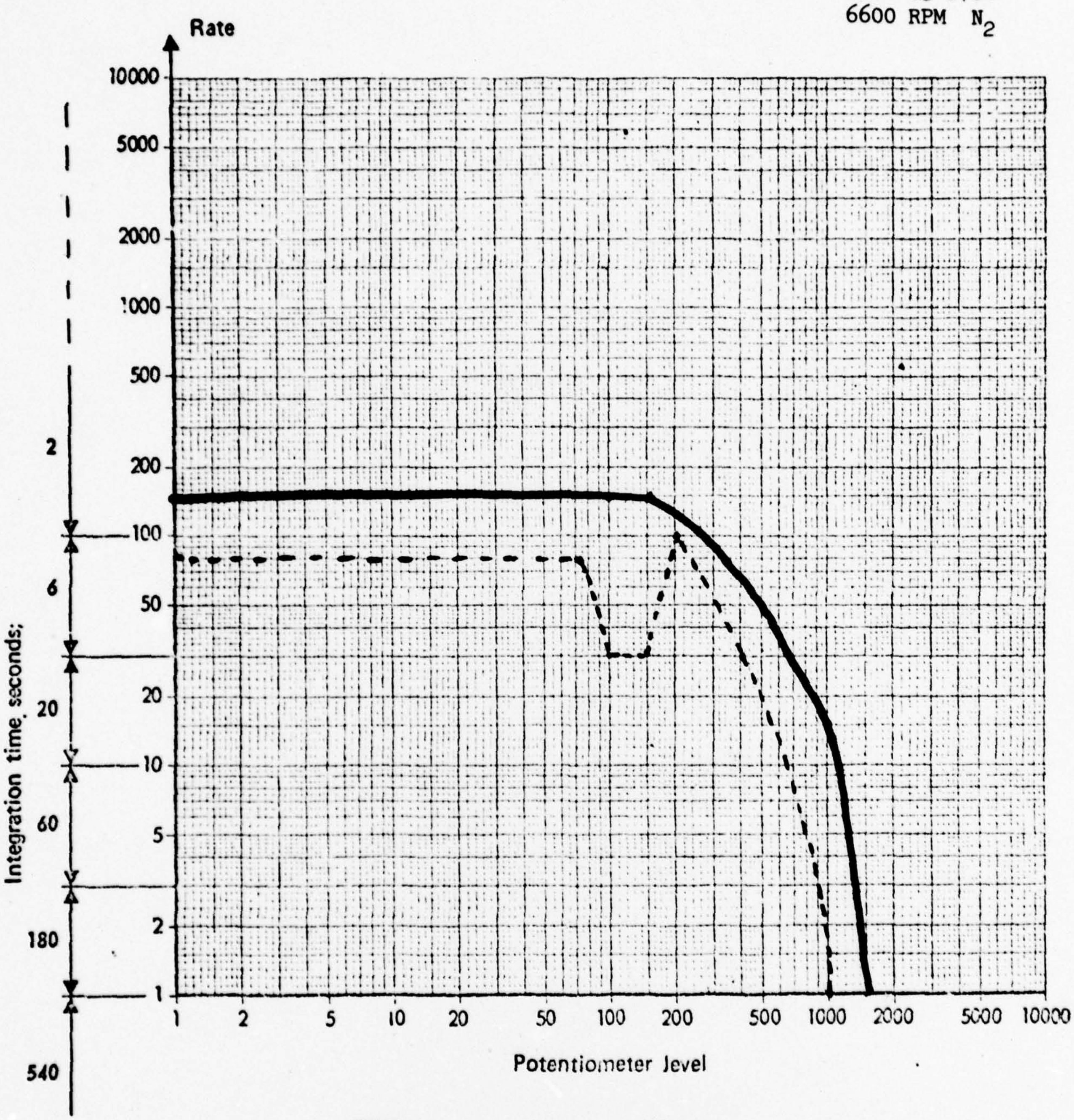
Figure 2

#3 Hanger Bearing

SN A20-36705

A/C 63-8784

6600 RPM N_2



NOTE: --------------- 4600 RPM

_______________ 6600 RPM

Figure 3

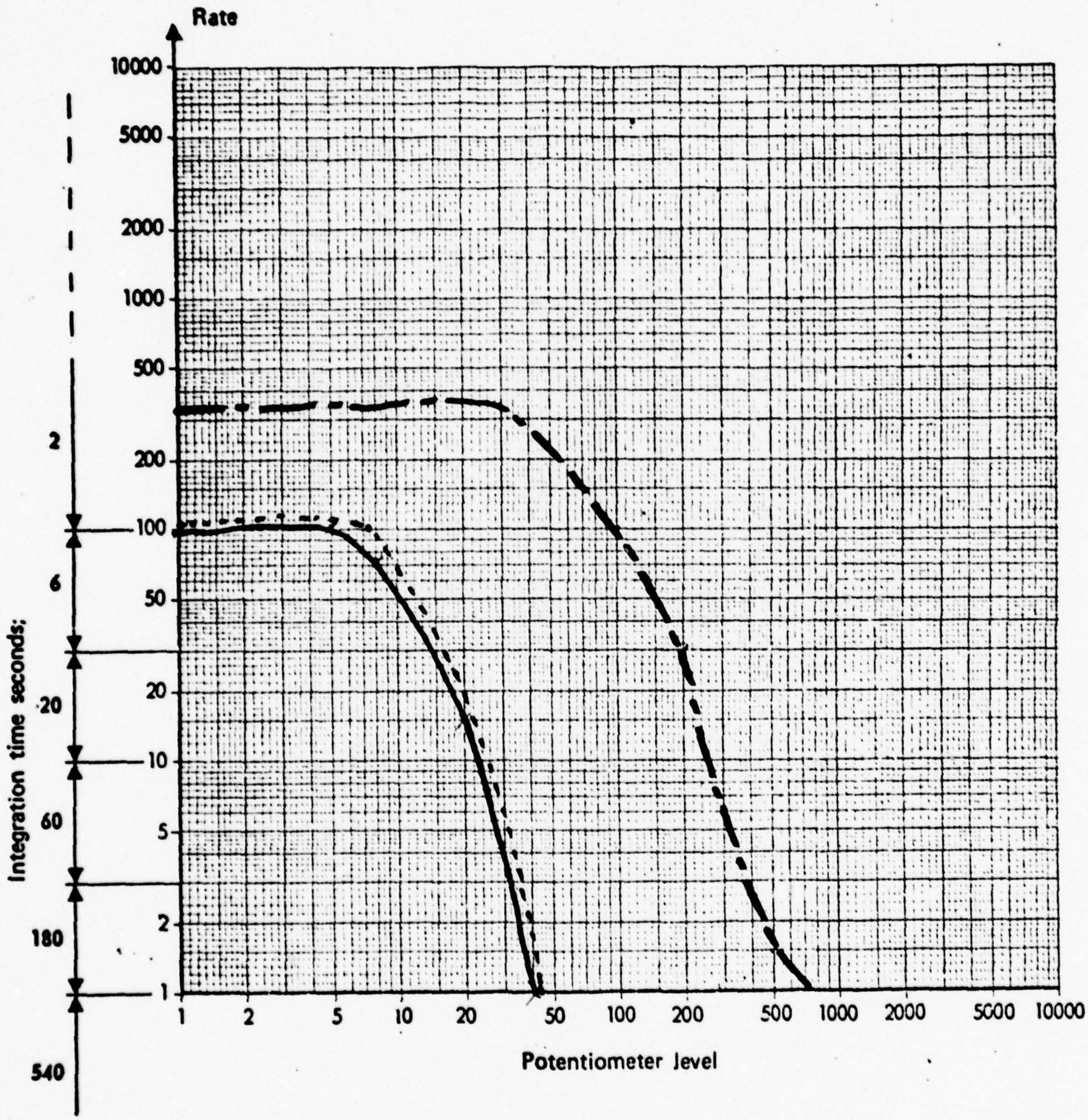
281st Aviation Company Bi State Airport 8 Aug 74

42° Gear Box Output

42° Gear Box Input A/C 65-9519 UH-1M

#1 Hanger Bearing 6600 RPM N_2

SN A20-44891



NOTE: 42° G/B Output ________________

42° G/B ----------------------

#1 Hanger Bearing _____ _ ______ _ ______

Figure 4

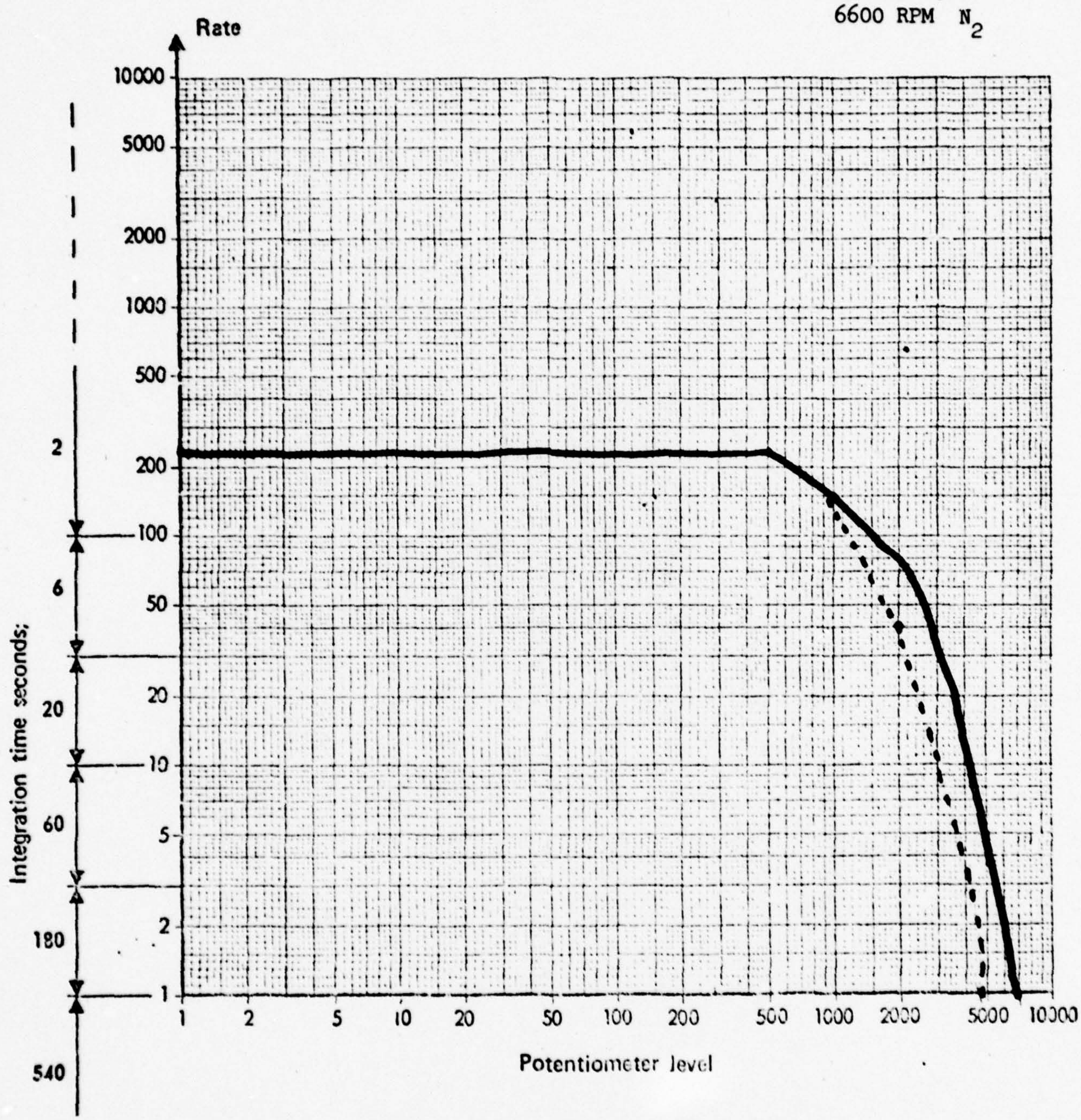
281st Aviation Company Bi State Airport 21 May 74

4 Hanger Bearing

SN A20-31435

A/C 63-8784

6600 RPM N_2



NOTE: ———————— 6600

-------------------- 4600

Figure 5

14

42° GEAR BOX ANALYSIS
SN B13-3243

The graphs of this 42° gear box show an abnormally high rate for the output drive quill and normal readings from the input drive quill.

The output drive quill roller bearing showed one scratch about 1/8" long in the outer race. All other damage was due to minor corrosion and pitting. The Duplex Bearing Set showed damage to the cages of both bearings due to inner race contact, some small scratches and minor corrosion.

The input drive quill roller bearing had evidence of very light pitting and corrosion. The Duplex Bearing Set showed heavy wear on the cage from inner race contact on one bearing. It is suspected that the other bearing in the set was worn excessively as there was a deviation in the ball path in the outer race and the bearing fell apart upon removal from the input quill housing. There was no other damage noted.

The gear set showed normal wear pattern.

42^{o} G/B

A/C #66-0630
FSN: 1615-918-2676
PN: 204-040-003-37
SN: B13-3243
TSN: 1735
TSO: 939

REMARKS: OUTPUT DRIVE QUILL:

Roller Bearing: PN: 204-040-310-1
SN: 21020

Outer Race: Scratch Approx 1/8" long •

Cage: Normal Wear

Inner Race: Minor Pitting

Rollers Normal Wear, minor corrosion, minor pitting

Duplex Ball Bearing: PN: 204-040-143-1
SN: 8199H-1

Outer Race: No Apparent Damage

Cage: Damage From Inner Race Contact

Inner Race: Small Scratches on Thrust Side

Balls: No Apparent Damage

Duplex Ball Bearing: PN: 204-040-143-1
SN: 8199H-2

Outer Race: Corrosion on Thrust Side

Cage: Damage From Inner Race Contact

Inner Race: No Apparent Damage

Balls: Minor Corrosion

INPUT DRIVE QUILL:

Roller Bearing: PN: 204-040-310-1
SN: 147403

Outer Race: Light Pitting and Corrosion
1 scratch

Cage: Normal Wear

Inner Race: Very Light Pitting

Rollers: Pitting & Corrosion

Duplex Ball Bearing: PN: 204-040-143-1
SN: 8112H-1

Outer Race: 1 Small Scratch on Thrust Side

Cage: Heavy Wear From Inner Race Contact

Inner Race: Corrosion

Balls: No Apparent Damage

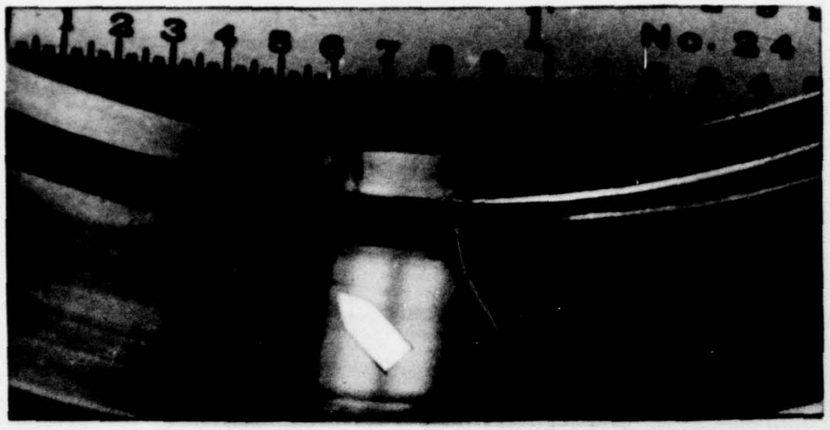
Duplex Ball Bearing: PN: 204-040-143-1
SN: 8112H-2

Outer Race: Deviation in Ball Path

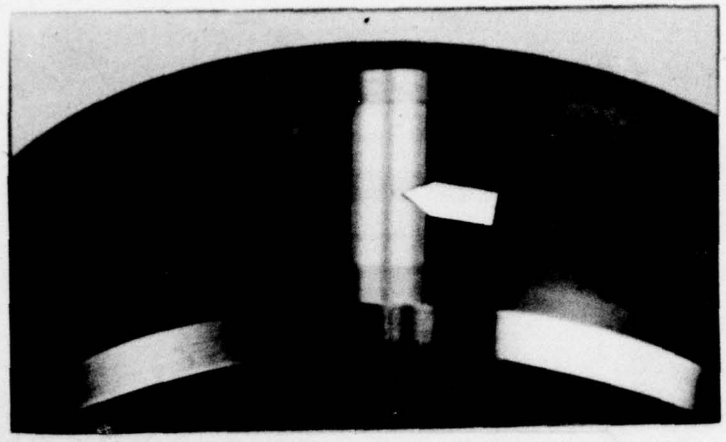
Cage: Normal Wear

Inner Race: No Apparent Damage

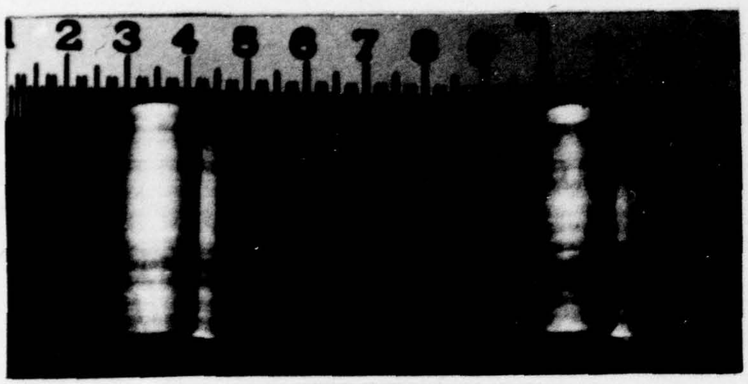
Balls: No Apparent Damage



Roller Bearing
S/N 21020
Outer Race



Roller Bearing
S/N 21020
Inner Race



Roller Bearing
S/N 21020
Rollers

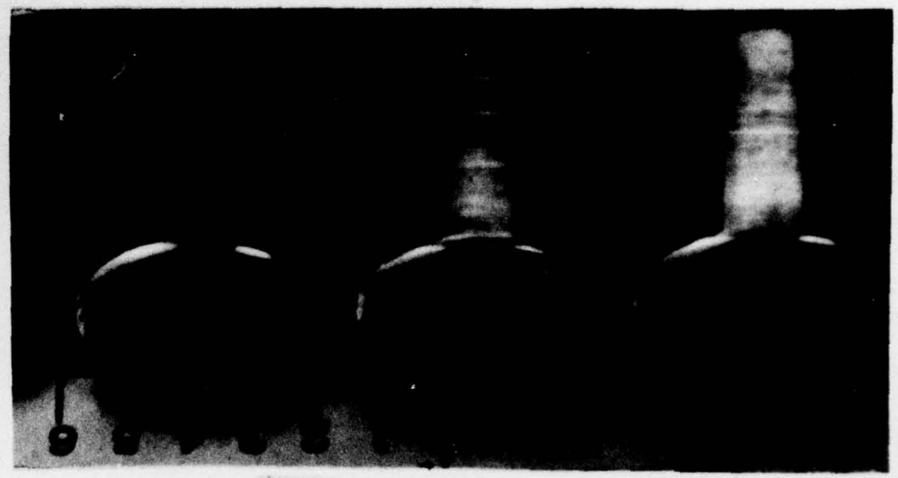
Duplex Ball Bearing
S/N 8199-H-1
Cage

19

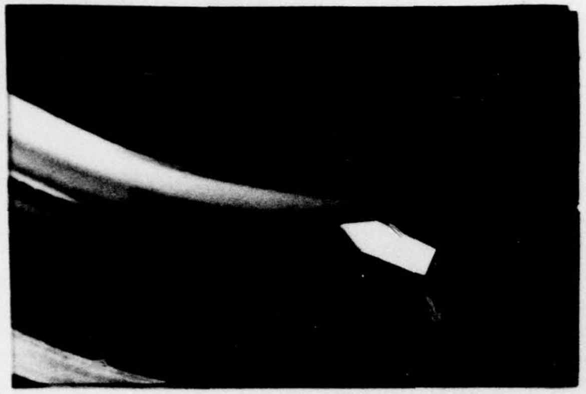
Duplex Ball Bearing
S/N 8199-H-2
Outer Race

Duplex Ball Bearing
S/N 8199-H-2
Cage

Roller Bearing
S/N 147403
Outer Race

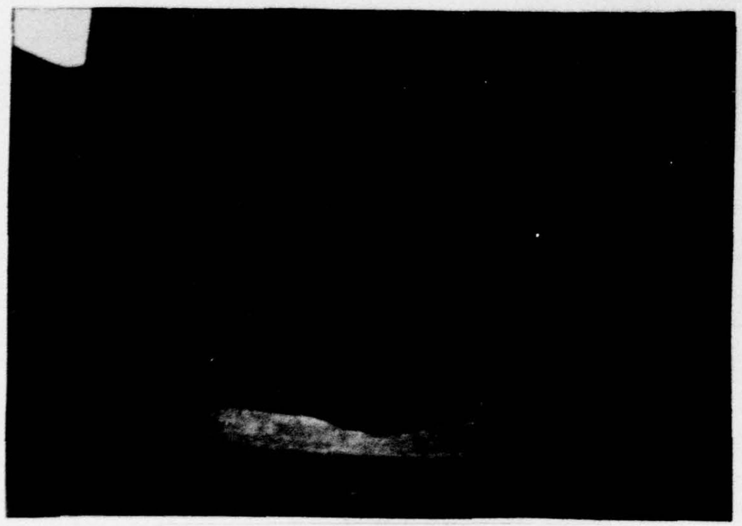


Roller Bearing
S/N 147403
Rollers

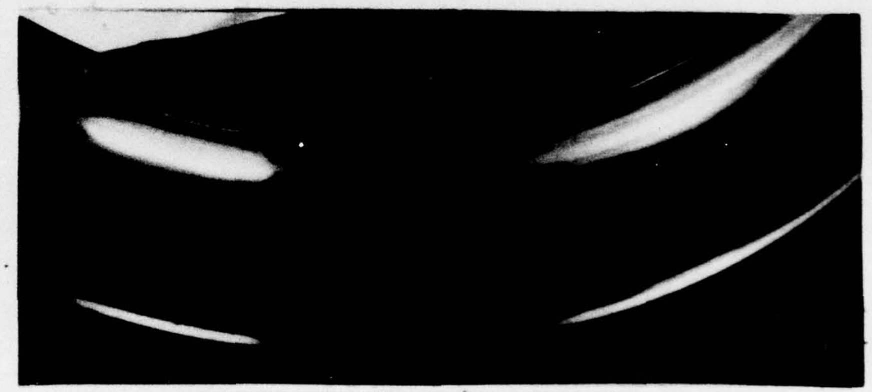


Duplex Ball Bearing
S/N 8112-H-1
Outer Race

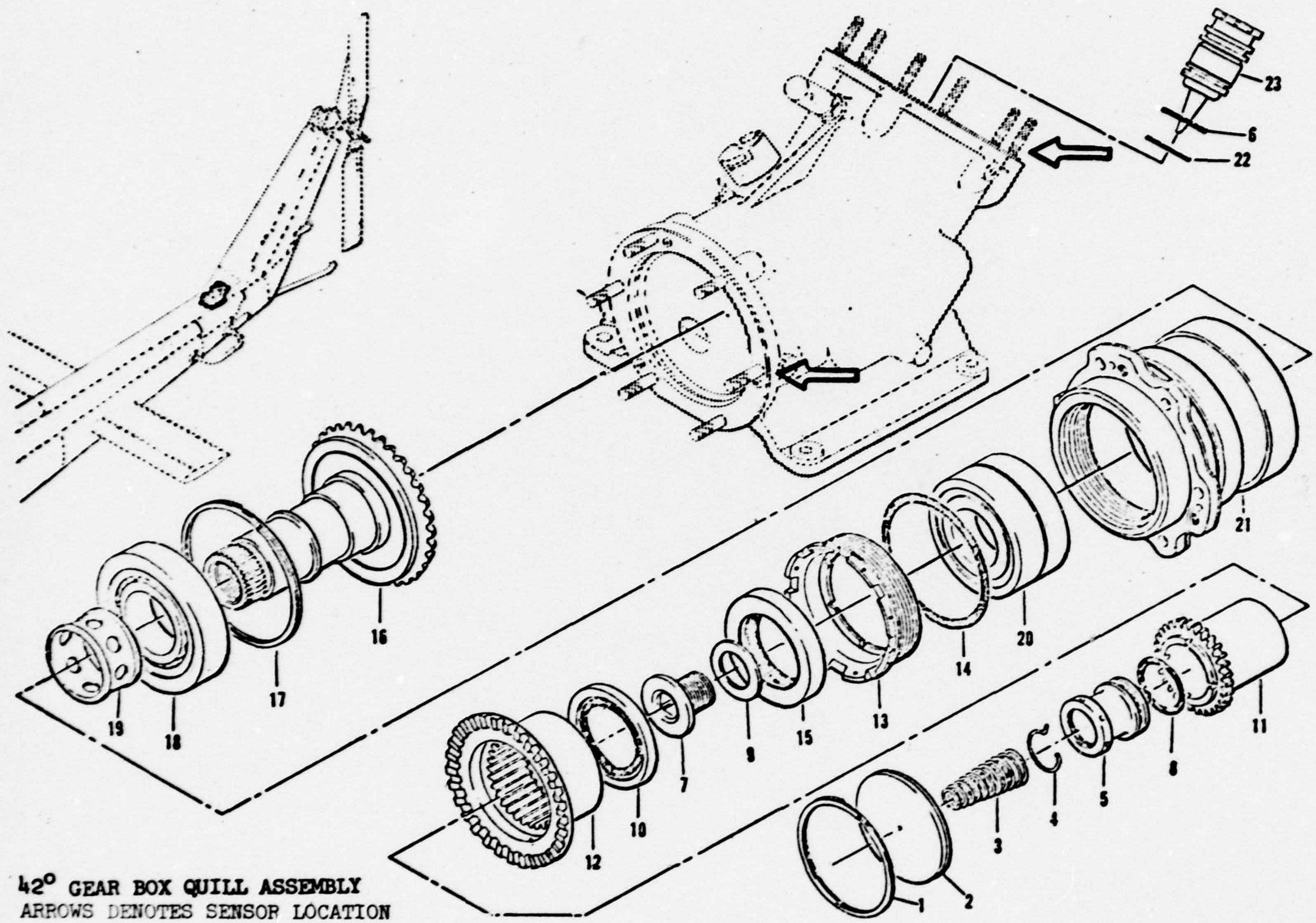
Duplex Ball Bearing
S/N 8112-H-1
Inner Race



Duplex Ball Bearing
S/N 8112-H-1
Cage



Duplex Ball Bearing
S/N 8112-H-2
Outer Race



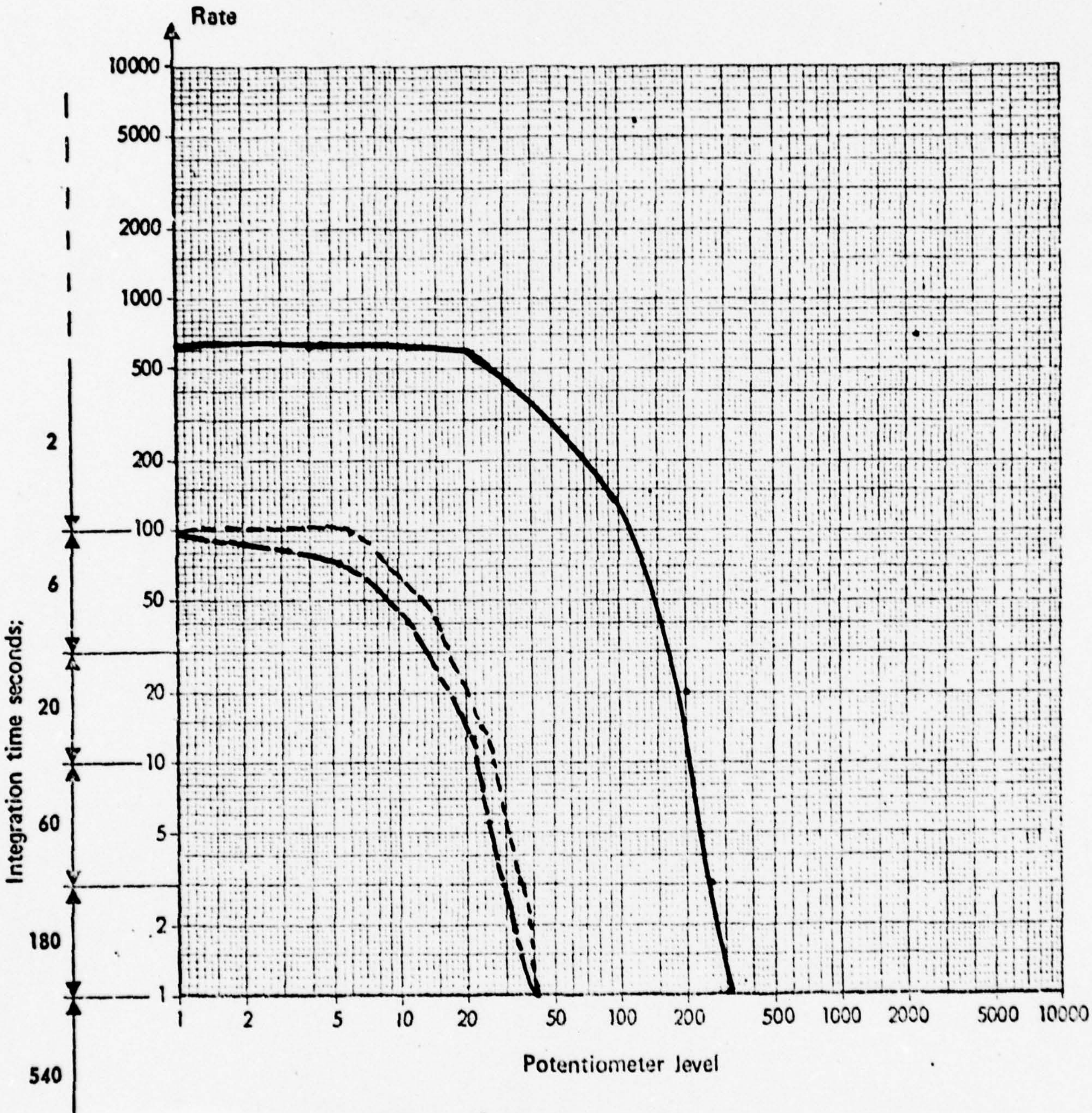
42° GEAR BOX QUILL ASSEMBLY
ARROWS DENOTES SENSOR LOCATION

Figure 6

281st Aviation Company Bi State Airport 6 Aug 74

90° Gear Box
42° Gear Box Input
42° Gear Box Output

A/C 60630 UH-1C
6600 RPM N_2



NOTE: 90° Gear Box — — — —
42° Gear Box Input - - - - - - - -
42° Gear Box Output ————

Figure 7

90° GEAR BOX TEARDOWN ANALYSIS

Three 90° gear boxes were observed having abnormal graphs but one gear box was torn down for analysis because only one newly overhauled gear box was available at the time. The other gear boxes will be torn down as soon as replacement gear boxes are made available.

The gear box was removed because of the growth noted in the rate and level while the data was being taken. This growth is usually indicative of damage progressing.

Analysis showed that the source of this growth was most likely caused by one of the Duplex Bearing Sets PN: 204-040-424-1. One bearing in the set had two large spalls in the outer race that apparently appeared recently as there was no continuous ball path through them. Also three spalls were observed in the inner race of the same bearing.

One small spall was found in the outer race of Duplex Bearing Set PN: 204-040-143-1.

All other damage was attributed to minor corrosion and pitting.

90° G/B

A/C: 69-15550
FSN: 1615-918-2677
PN: 204-040-012-13
SN: ABC-5688
TSN: 588
TSO: 400

REMARKS: Small Duplex Bearing: PN: 204-040-424-1
SN: 21262

Outer Race: 2 Spalls, Burred Around Edges

Inner Race: 3 Spalls, Evidence of False Brinnelling

Balls: No Apparent Damage

Small Duplex Bearing: PN: 204-040-424-1
SN: 21262

Outer Race: No Apparent Damage

Inner Race: No Apparent Damage

Balls: No Apparent Damage

Small Roller Bearing: PN: 204-040-406-1
SN: 203462

Outer Race: 2 Small Scratches

Inner Race: No Apparent Damage

Rollers: 1 Roller Slightly Scratched

Duplex Bearing: PN: 204-040-143-1
SN: 12620

Outer Race: 1 Small Spall

Inner Race: No Apparent Damage

Cage: No Apparent Damage

Balls: No Apparent Damage

Duplex Bearing: PN: 204-040-143-1
SN: 12620

Outer Race: Mild Corrosion and Pitting

Inner Race: Mild Corrosion and Pitting

Cage: No Apparent Damage

Balls: No Apparent Damage

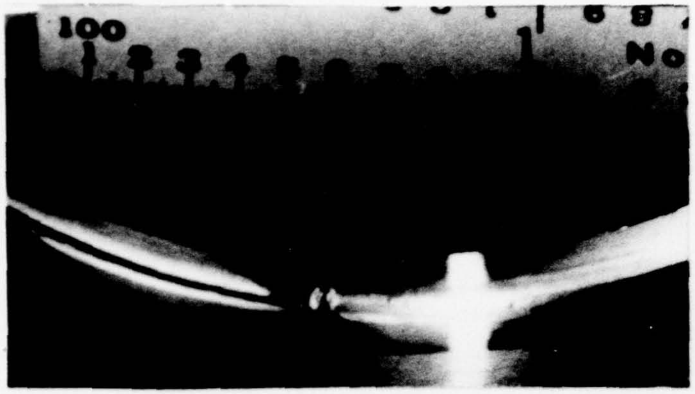
24

Roller Bearing: PN: 204-040-407-3
SN: 23475

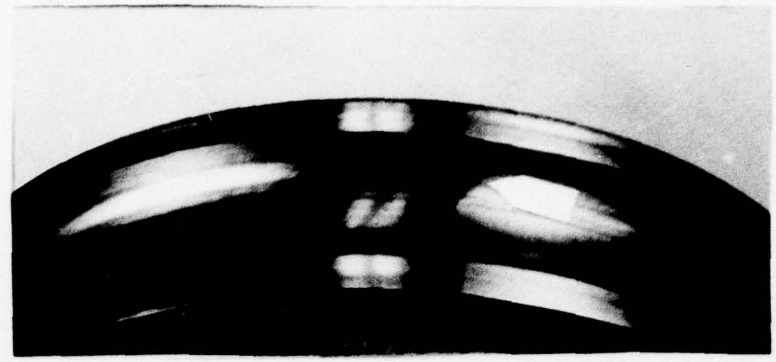
Outer Race: Mild Pitting, Scratches Parallel to Race

Inner Race: Scratches Parallel to Race

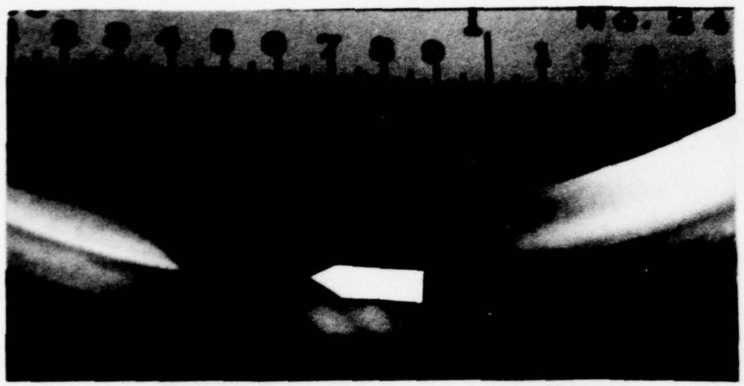
Rollers: No Apparent Damage



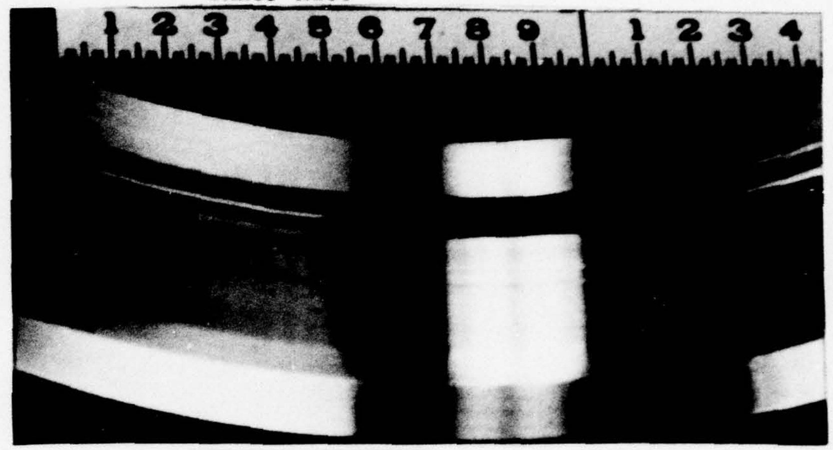
Small Duplex Bearing
S/N 21262
Outer Race



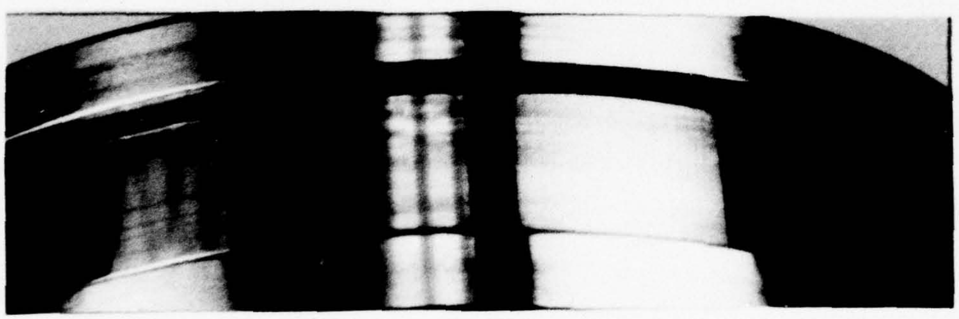
Small Duplex Bearing
S/N 21262
Inner Race



Duplex Bearing
S/N 12620
Outer Race

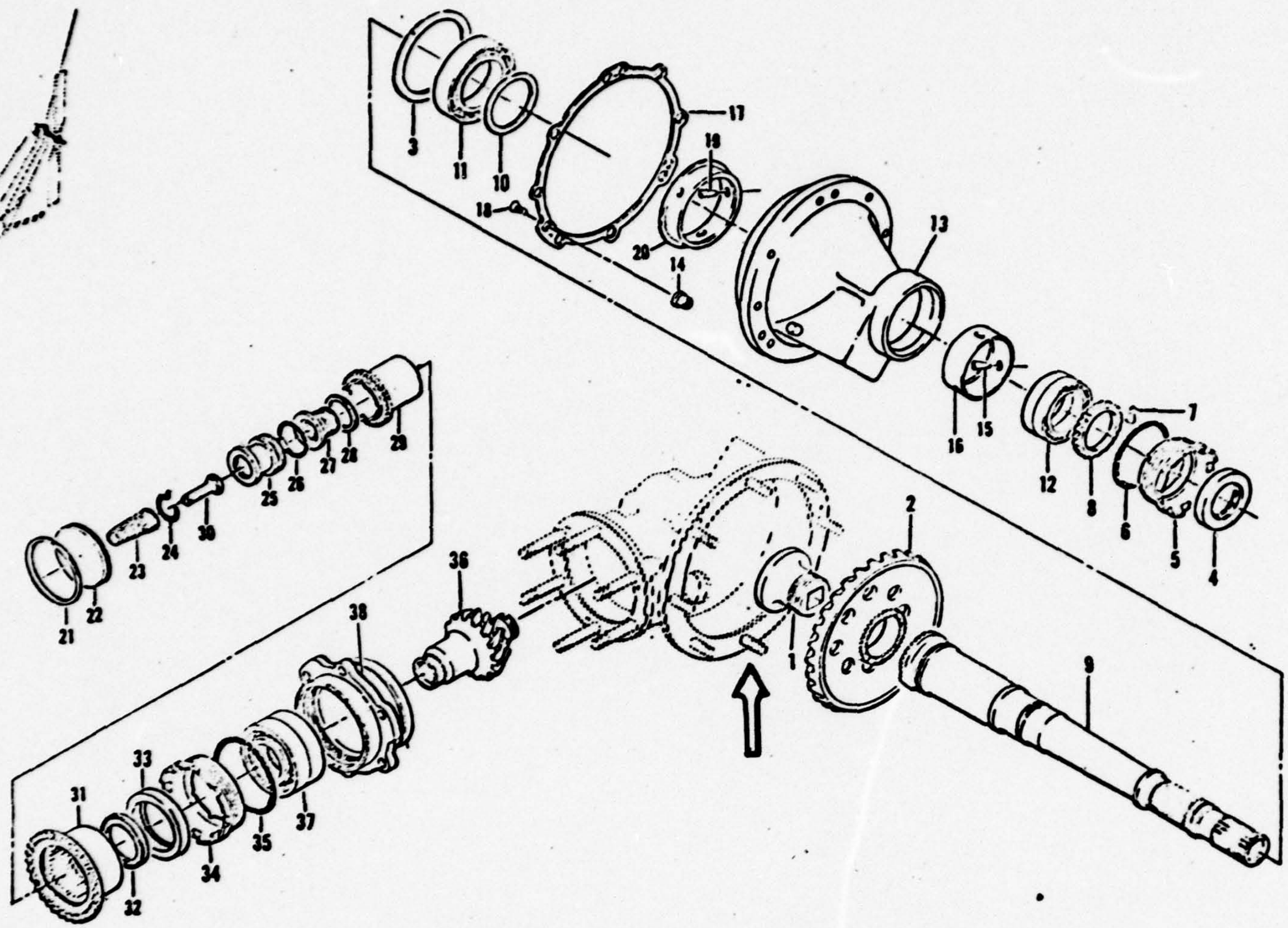


Roller Bearing
S/N 23475
Outer Race



Roller Bearing
S/N 23475
Inner Race

26



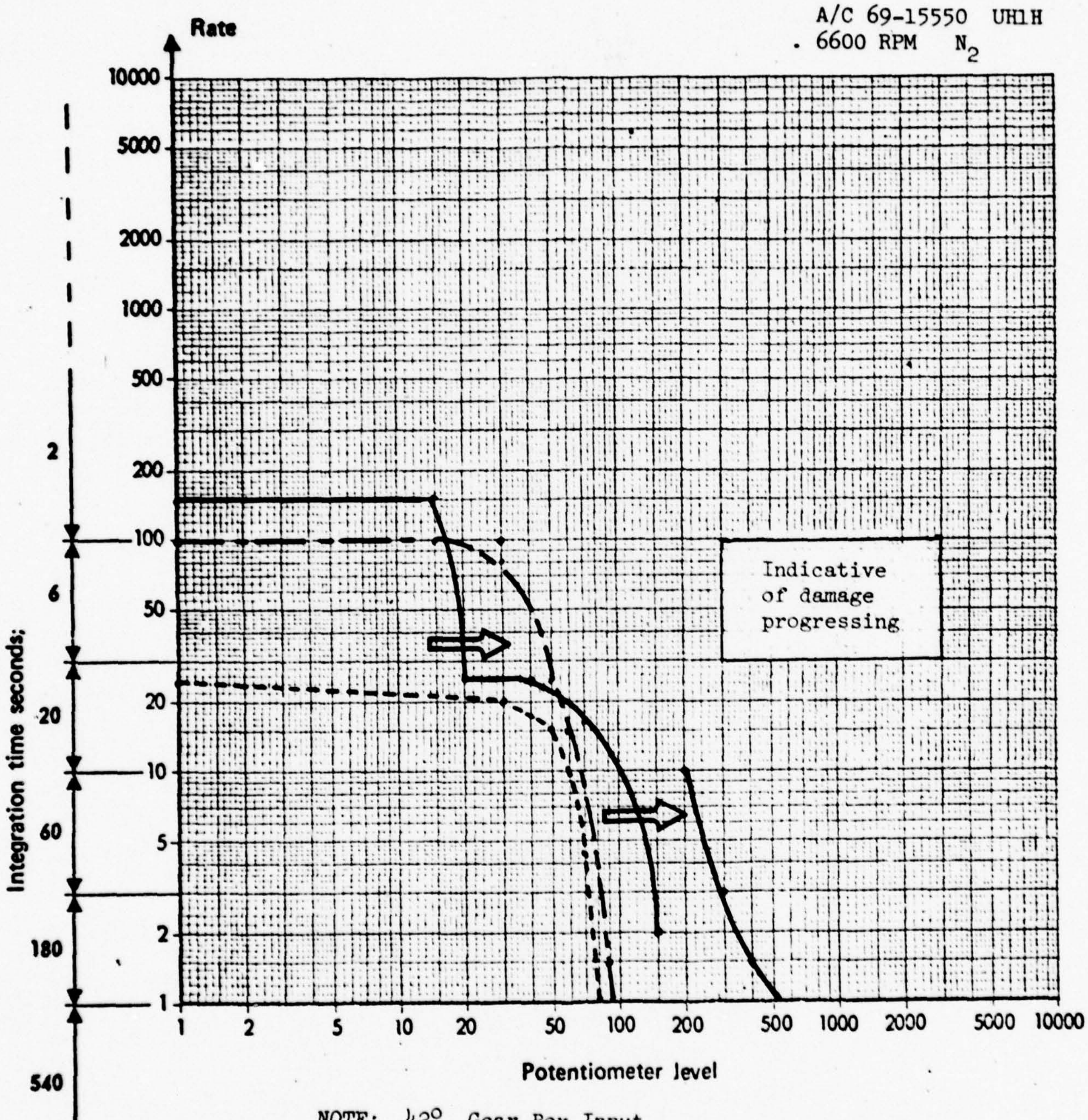
90° GEAR BOX QUILL ASSEMBLY
ARROW DENOTES SENSOR LOCATION

Figure 8

281st Aviation Company Bi State Airport 30 Jul 74

42° Gear Box Input } Portside
42° Gear Box Output }
90° Gear Box Case Half Mount Bolt

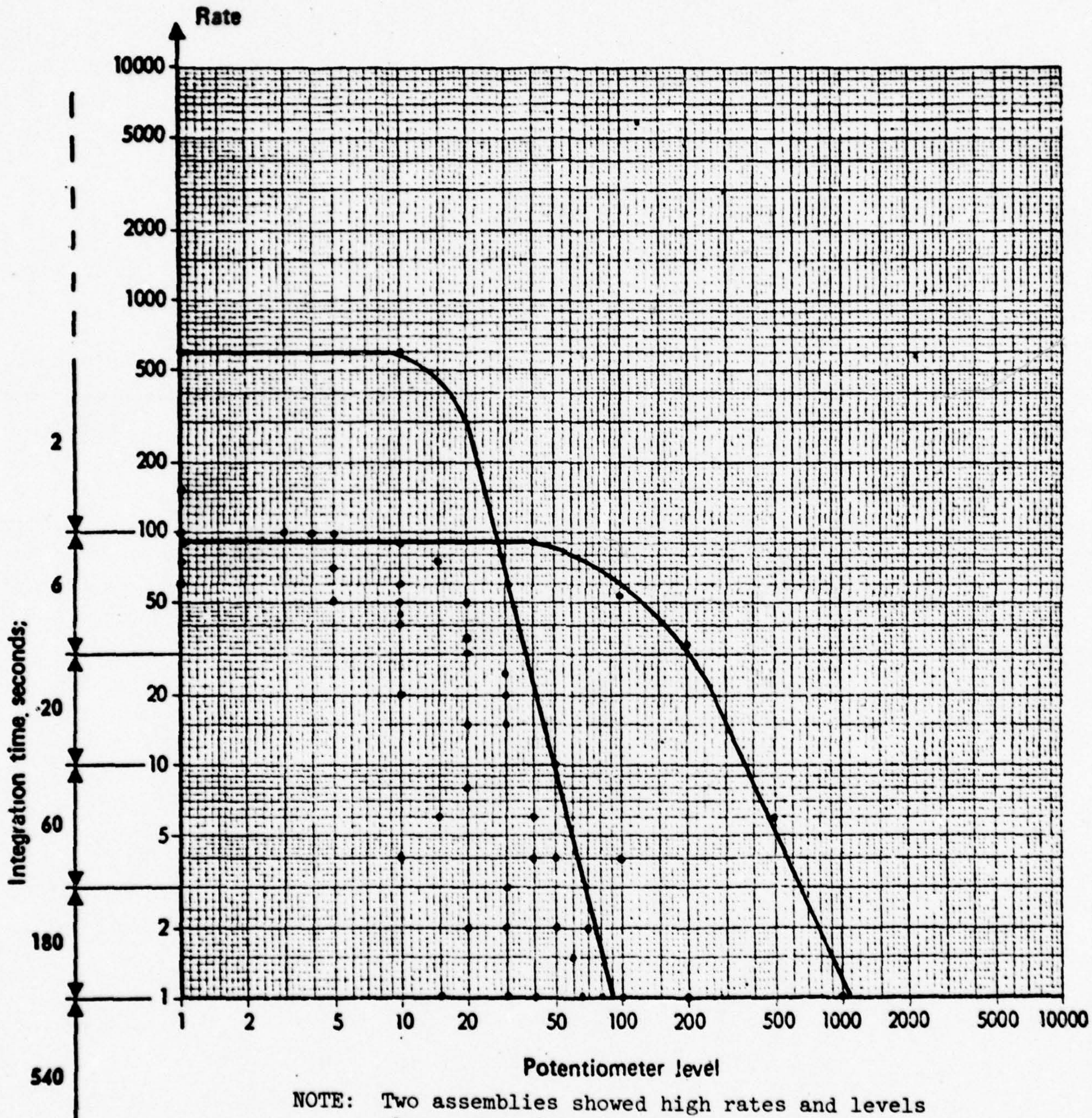
A/C 69-15550 UH1H
. 6600 RPM N_2



NOTE: 42° Gear Box Input — — — — —
42° Gear Box Output ----------------
90° Gear Box ________________

Figure 9

SUMMARY CHART OF 10 90° GEAR BOX
ASSEMBLIES SHOWING DATA SCATTER



NOTE: Two assemblies showed high rates and levels when compared to the general seatter

2.2 FORT RUCKER AIDAPS HELICOPTER DATA

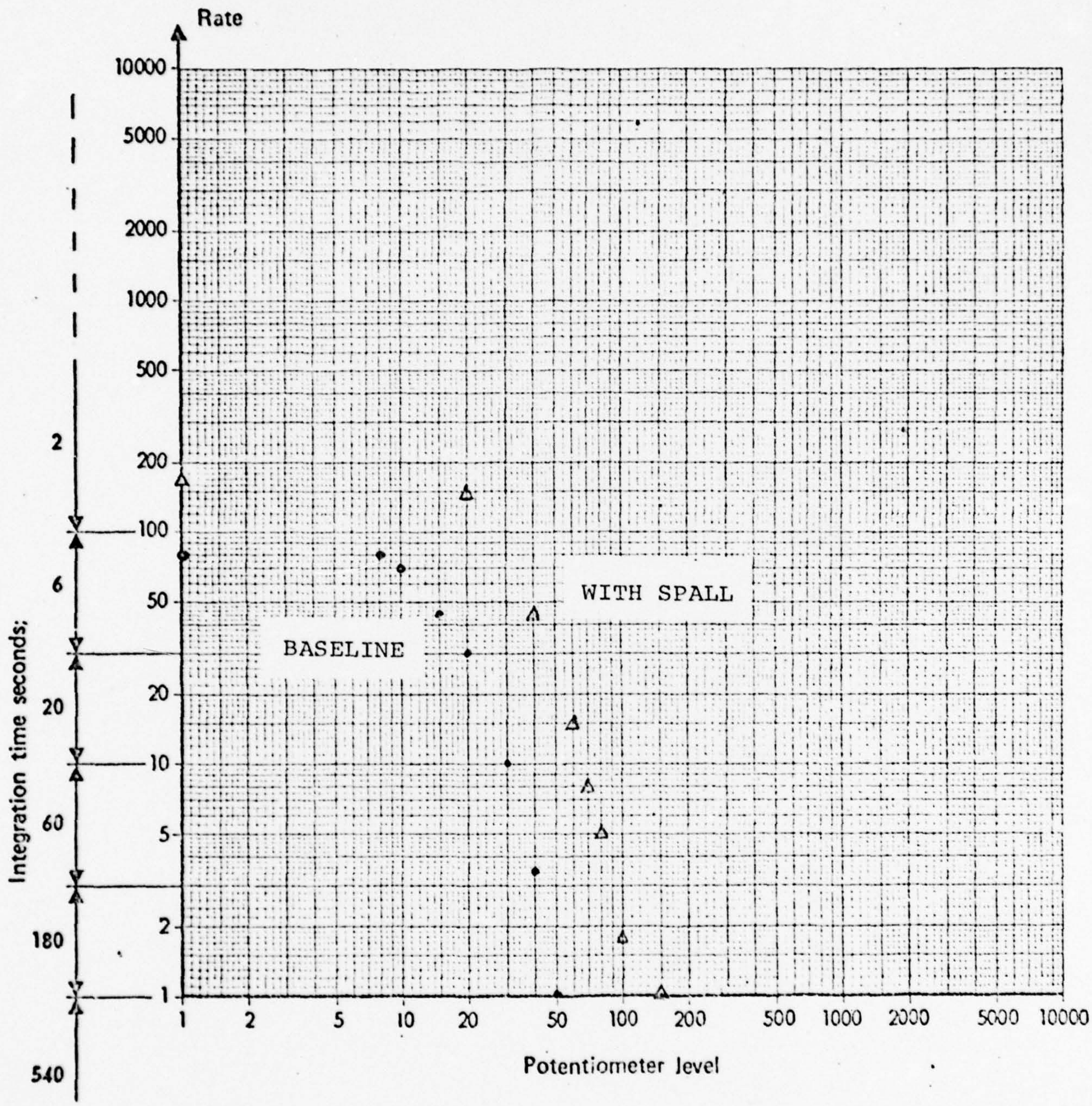
The data collected on the AIDAPS helicopters was from gear boxes of known condition. Each gear box was completely disassembled, inspected, and any necessary component replacement accomplished prior to reassembly and use in the program. The data included that from an implanted input quill duplex bearing (item 20, Figure 6) with known defects.

Figure 11 shows the shock pulse curve for the "sanitized" gear box as well as one with an implanted duplex bearing. In this case, the outboard half of the duplex bearing had a single spall in the outer race, 0.14" x 0.14", with a definite depth; the inboard half had some corrosion caused pitting with one pit in the ball's path. This damage was classified in category C which corresponds to moderate spalling.

A second duplex ball bearing, this one with a single shallow spall approximately 0.08" x 0.08" in the outer race, was implanted in another 42^{o} gearbox. Of particular interest was the observation of progressive damage while the test was in progress. The shape of the shock emission curve changed continuously over a period of minutes in both rate and shock level. Figure 12 shows two curves developed on a single run. A change in slope takes place (A), a sharp increase in rate (B-C), a continually change in slope (C-D). Without shutting down the engine, the second curve (E-F-G) was developed. After engine shut-down, an oil sample analysis revealed traces of metal, although not beyond that deemed unacceptable. The dotted line is an extrapolation of the initial slope and gives an indication of the shock level stabilizing at a factor of ten higher. Two more runs were made which essentially repeated curve E-F-G. Teardown analysis showed that the original degradation had not changed noticeably but that new spalls were found on the outer race and on one ball bearing.

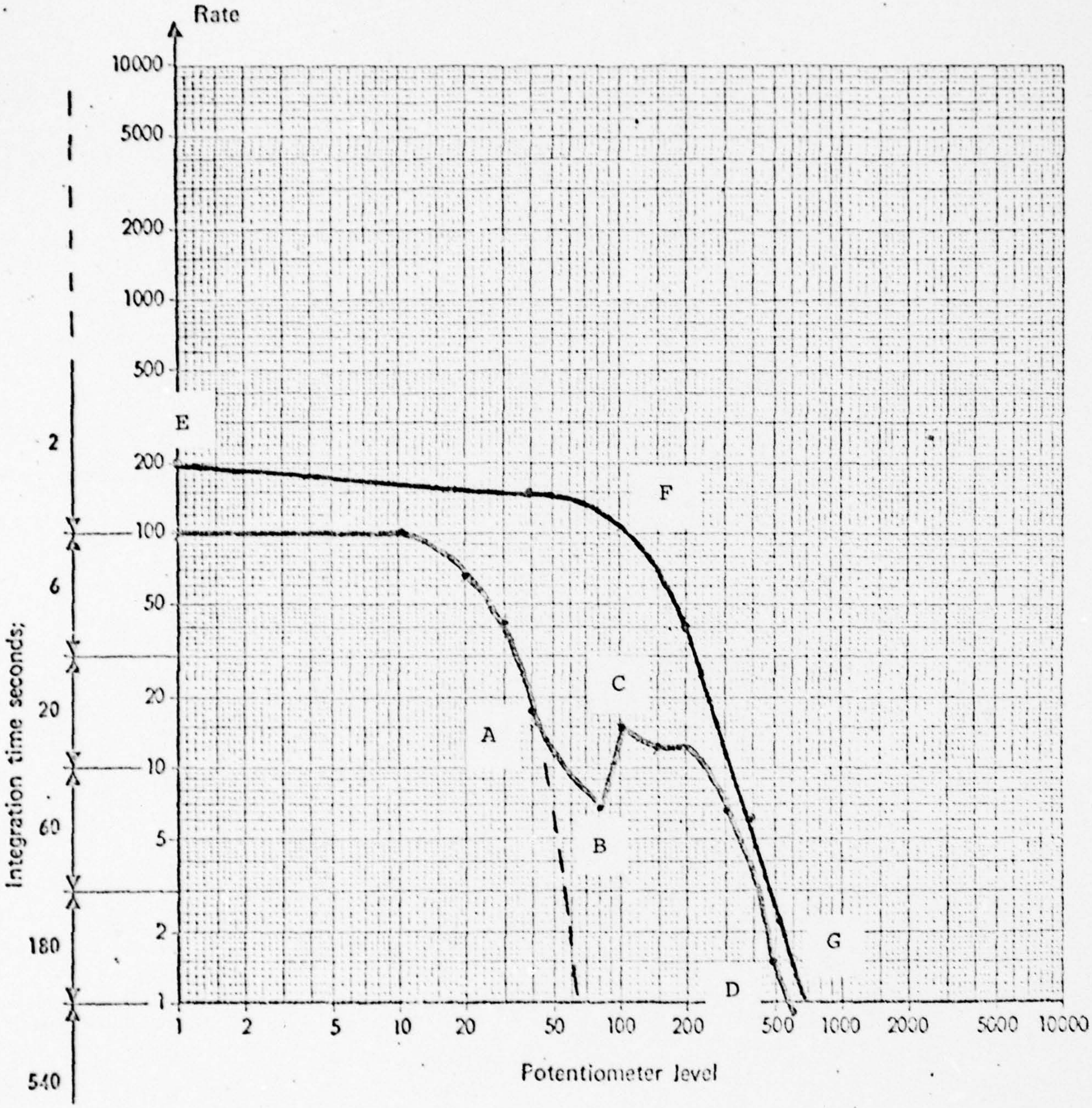
Additional data was collected on hanger bearings installed on helicopters involved in the AIDAPS program at Fort Rucker. These hanger bearings were inspected and found acceptable prior to their use in that program. Figure 13 shows the effect of engine rpm variation and anti torque pedal (tail rotor) inputs on the number 4 hanger bearing. The difference between flight idle data and that at 6400 and 6600 is apparent. At a given N_2, rudder pedal deflection gives a slight increase in the potentiometer level generally shifting the shock pulse curve to the right. Similar results were obtained on the number 3 hanger bearing.

Additional data is in Appendix 2.2.



COMPARISON OF BASELINE AND
DEGRADED GEARBOX (IMPLANTED
WITH SPALLED DUPLEX BEARING)

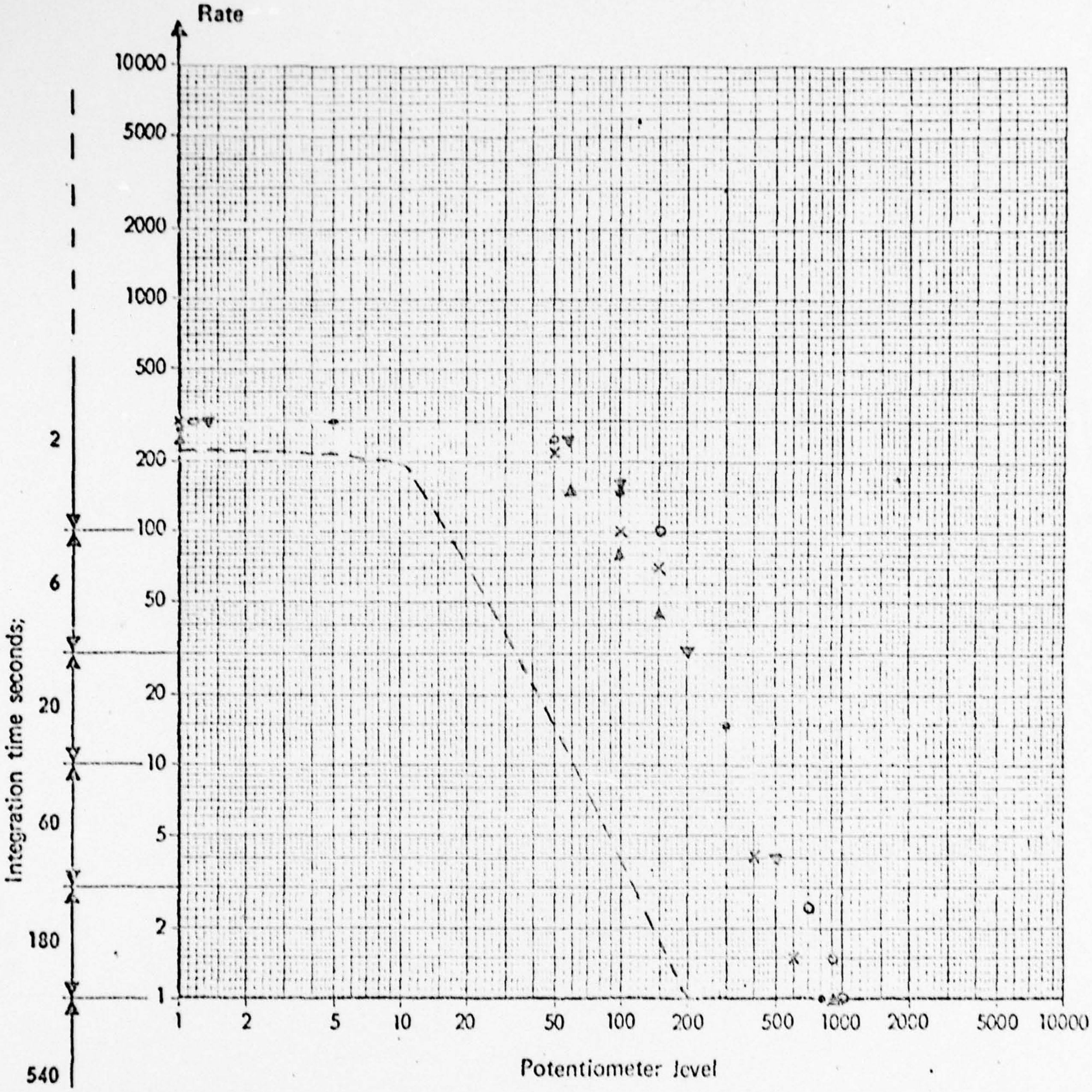
Figure 11



42° GEARBOX IMPLANTED WITH A SPALLED DUPLEX BALL BEARING

EVIDENCE OF DAMAGE PROGRESSING

Figure 12



TIE-DOWN TESTS FORT RUCKER, AL.

BEARCAT 14 (S/N 65-9846)

run	symbol	engine rpm	rudder pedal
1	----	flight idle	neutral
2	•	6400	full right
3	▲	6400	full left
4	x	6600	neutral
5	o	6600	full right
6	▼	6600	full left

Figure 13

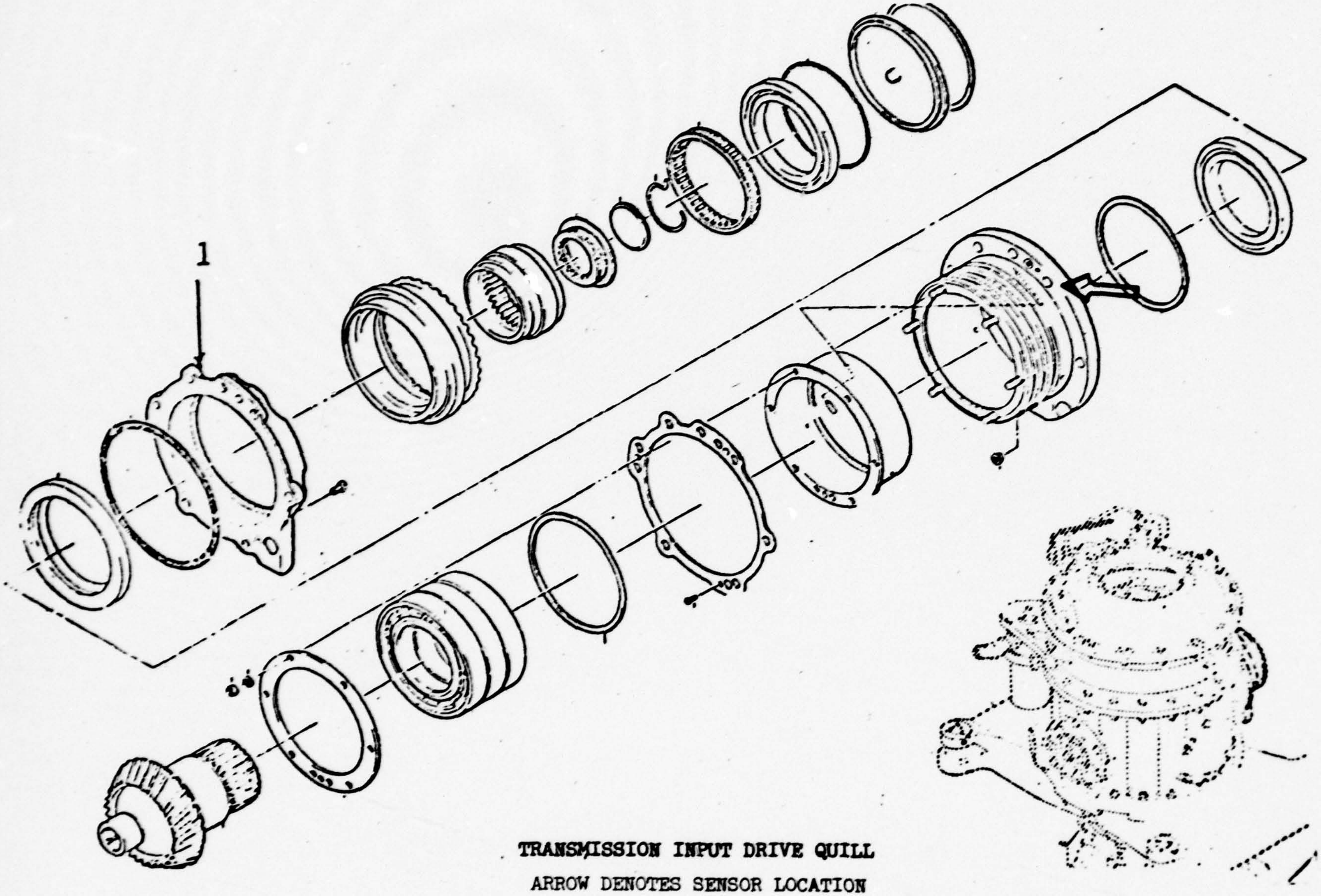
2.3 TRANSMISSION SHOCK PULSE ENVELOPES

Shock pulse data was collected from two locations on the transmission. Figures 14 and 15 show the attachment point for the transmission input drive quill and for the mast bearing assembly. Figure 16 is a scatter diagram of nine different transmissions with the accelerometer attached to the input drive quill. The dotted line is that recorded from Bearcat 13 at Fort Rucker, Alabama. This is the only transmission of known good condition, having been inspected prior to its use in the AIDAPS program. One of the transmissions installed on UH-1C 66-15071 indicates a much higher rate and level than the others.

Figure 17 shows a scatter diagram for nine transmissions with data collected at the mast bearing assembly. Again, in this figure, the dotted line is from Bearcat 13. The single exceptional high rate and level readings is the same transmission that indicated the high reading from the input drive quill.

It was beyond the scope of work to remove and disassemble a transmission. However, past history has shown that exceptionally high readings above the norm generally indicate degraded components. There is no way to determine the level of degradation nor to isolate it within the transmission.

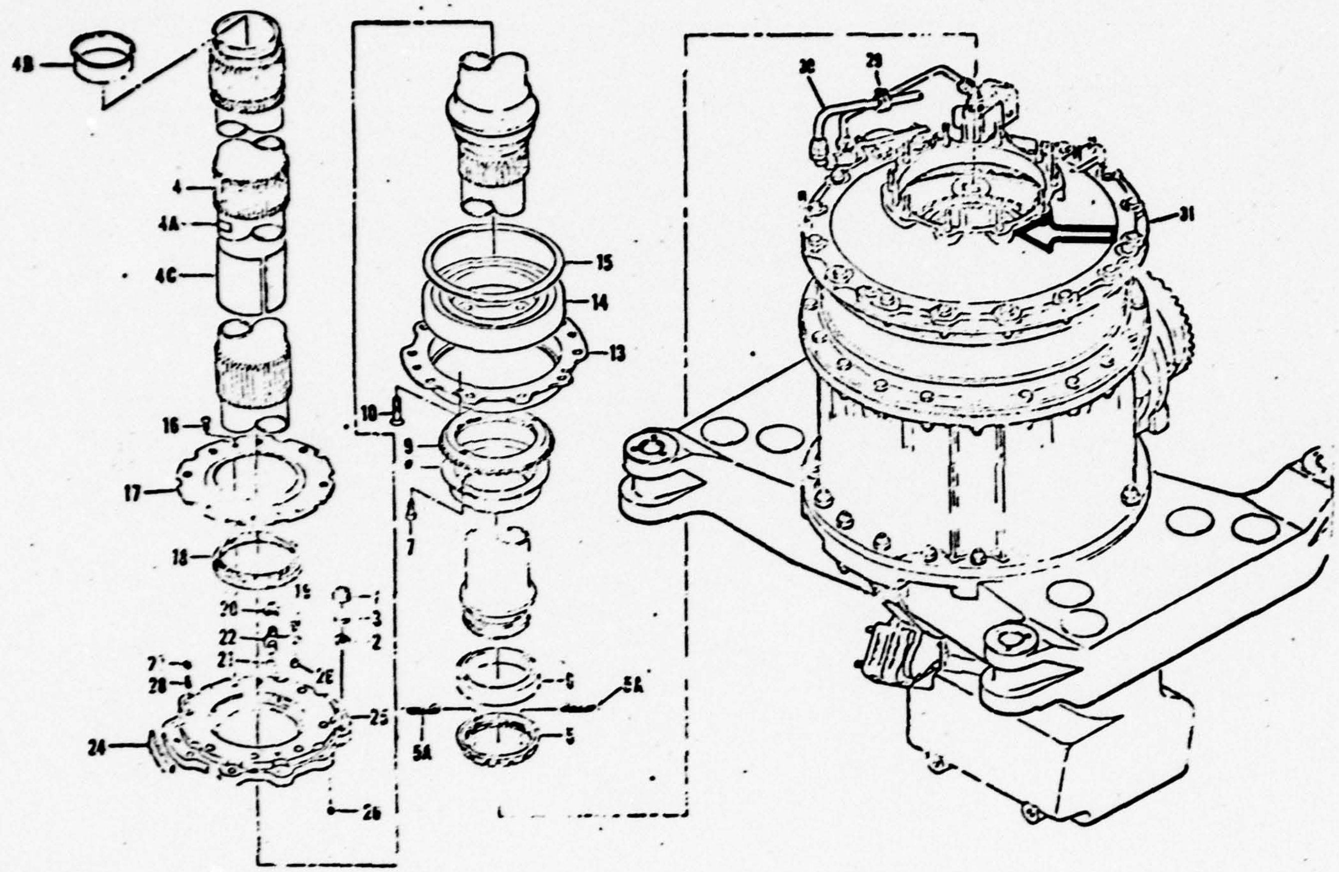
Figure 18 indicates the effect of sensor location on the shock envelope of the mast bearing reading. The accelerometer is normally mounted on the portside. Forward and starboard locations, when compared to the usual mounting exhibit only minor variations; the aft location varies by a factor of two at the higher potentiometer levels.



TRANSMISSION INPUT DRIVE QUILL

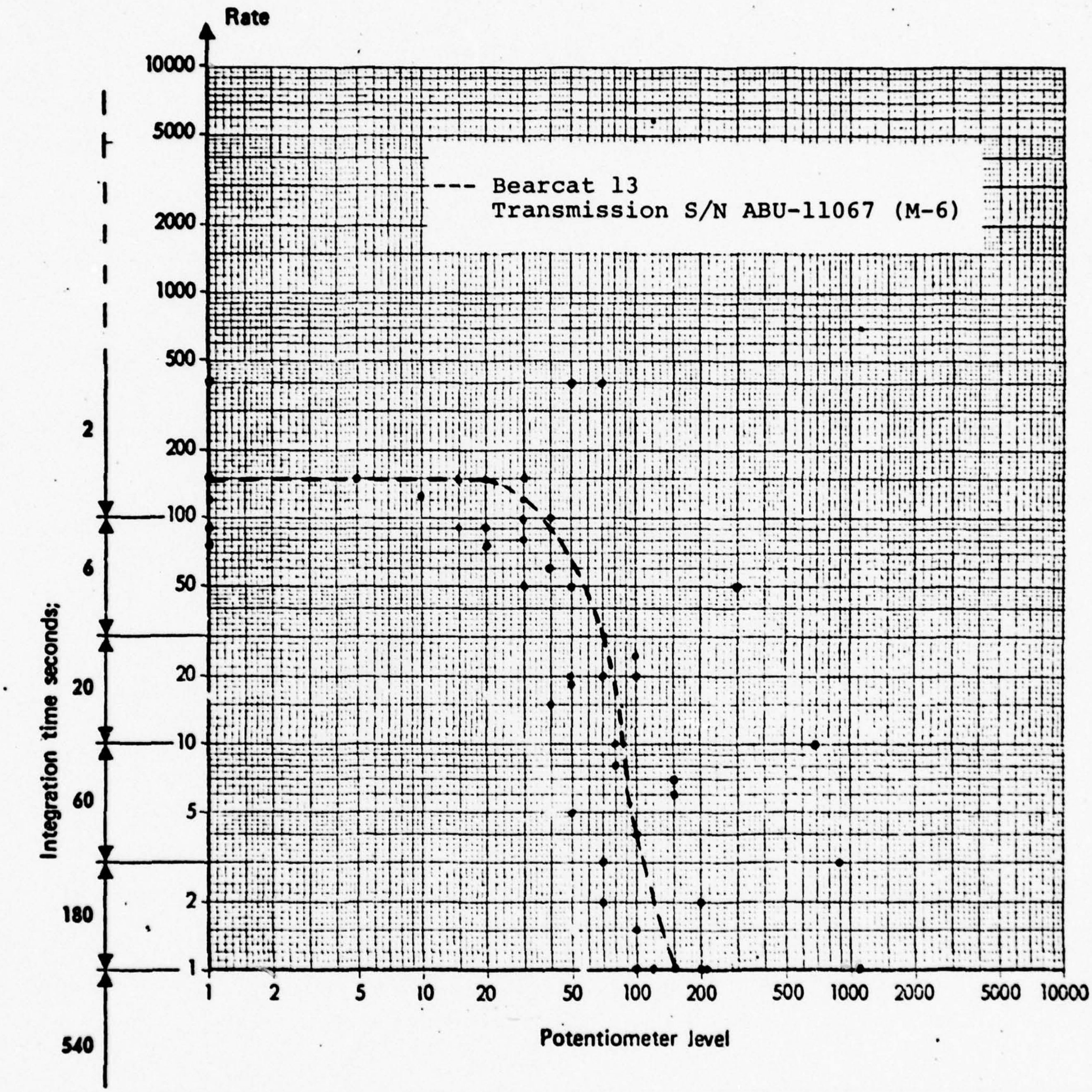
ARROW DENOTES SENSOR LOCATION

Figure 14



MAST BEARING ASSEMBLY
ARROW DENOTES SENSOR LOCATION

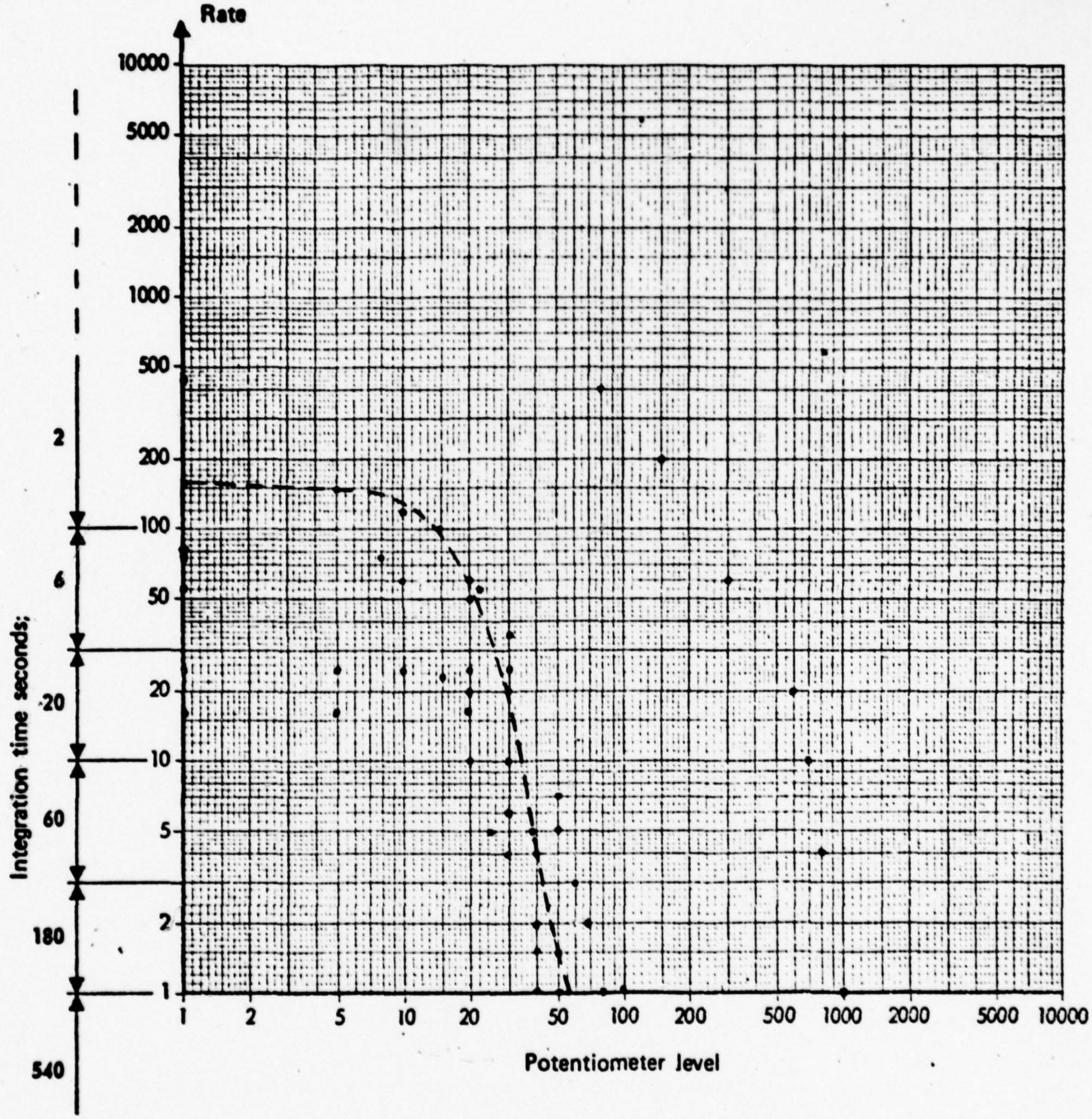
Figure 15



Scatter Diagram
Transmission Input Drive Quill;
Ground Runs, N_2 = 6600 RPM.

Figure 16

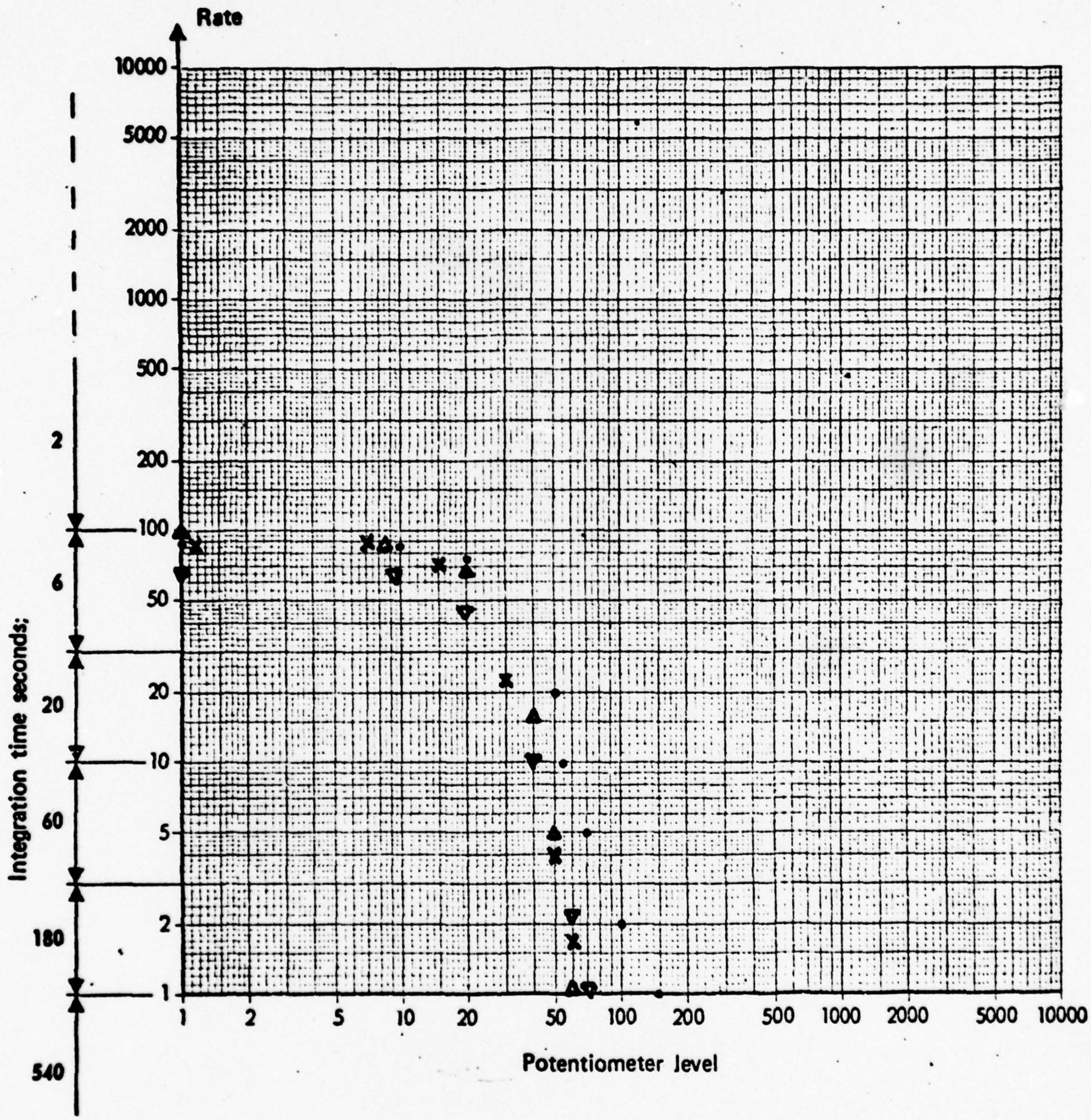
--- Bearcat 13
Transmission S/N ABU-11067 (M-6)



Scatter Diagram
Transmission Mast Bearing Assembly

Figure 17

. Aft
Δ Starboard
∇ Forward
x Port (Normal Attachment)



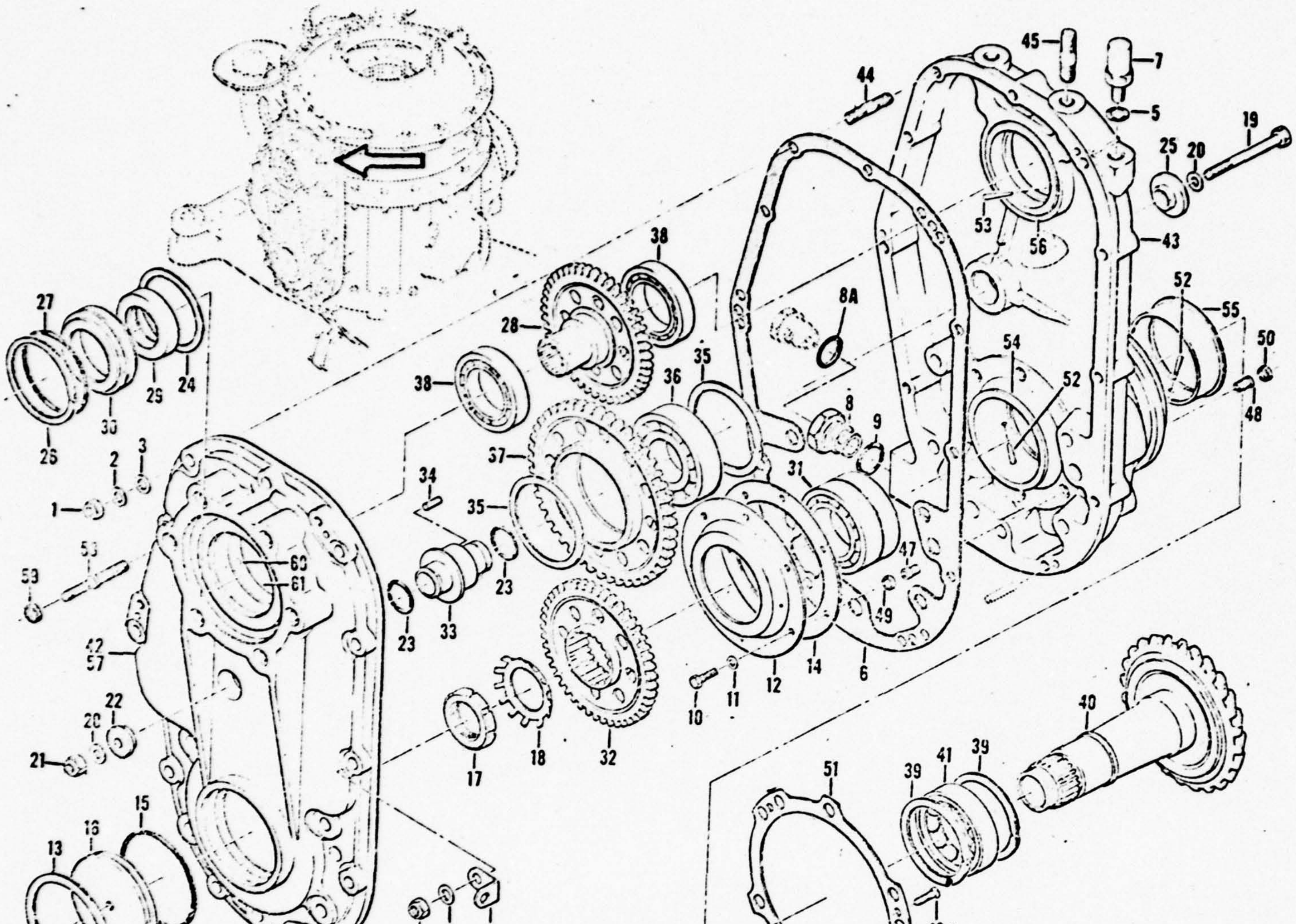
Effect of Sensor Mounting
On Mast Bearing Reading

Figure 18

2.4 GENERATOR OFFSET QUILL ASSEMBLY

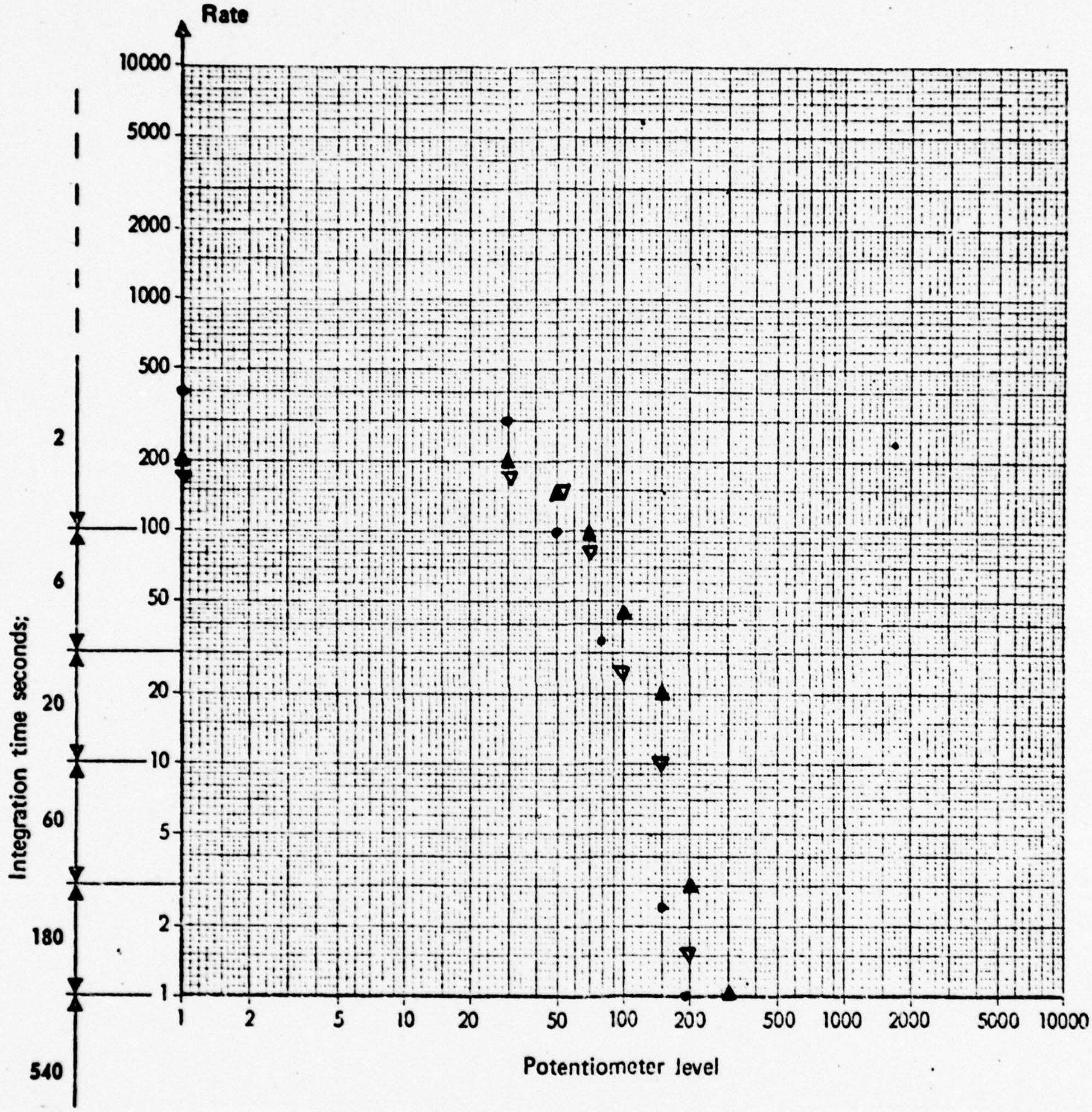
Shock pulse data was collected from the generator offset quill assembly shown in Figure 20 . With the assistance of the Ohio State Research Department, data was recorded on good, as well as implanted, gears in this assembly which was undergoing laboratory tests under an AVLABS contract. Figure 20 shows the shock emission curves for the good and artificially damaged gears. No appreciable difference was noted in the two curves. This could be attributed to an inherent limitation of the MEPA-10 to detect gear damage in this particular assembly, considering: 1) the type of damage artificially implanted; 2) the severity of damage; 3) the contact of the damaged component with other gear elements.

Also shown on Figure 20 is single envelope taken from an assembly as installed on a UH-1H. Although both laboratory and aircraft installed assemblies were operated at approximately the same rpm, there are only minor differences in rate and levels. As these are two different assemblies, with the aircrafts component being of unknown condition, no general conclusions should be inferred.



GENERATOR OFFSET QUILL
ASSEMBLY
Arrow Denotes Sensor Location

Figure 19



GENERATOR DRIVE GEAR

- ● UH-1H 70-16354
- ▲ Laboratory test; undamaged gear
- ▽ Laboratory test; damaged gear

Figure 20

2.5 OH-58 DATA

Readings were taken on an OH-58 tail rotor drive train in order to show feasibility. Data collection was limited as there are only two OH-58 Helicopters in the St. Louis Area. Also the OH-58 has two types of hanger bearing mounts and a new sensor mount would have to be developed in order to take readings on all hanger bearings.

Only one of the two OH-58's in the St. Louis Area had hanger bearing mounts compatible to the sensor mount so six hanger bearing readings were taken.

A reading was also taken on the 90° gear box. There were no attachment problems encountered.

No definite conclusions can be drawn due to the lack of data and teardown analysis.

AVSCOM FLIGHT DETACHMENT
St. Louis International Airport

18 Sep 74

OH-58-A
A/C# 72-21418
T/R 6180 RPM
Main Rotor 350 RPM
N_2 - 103%

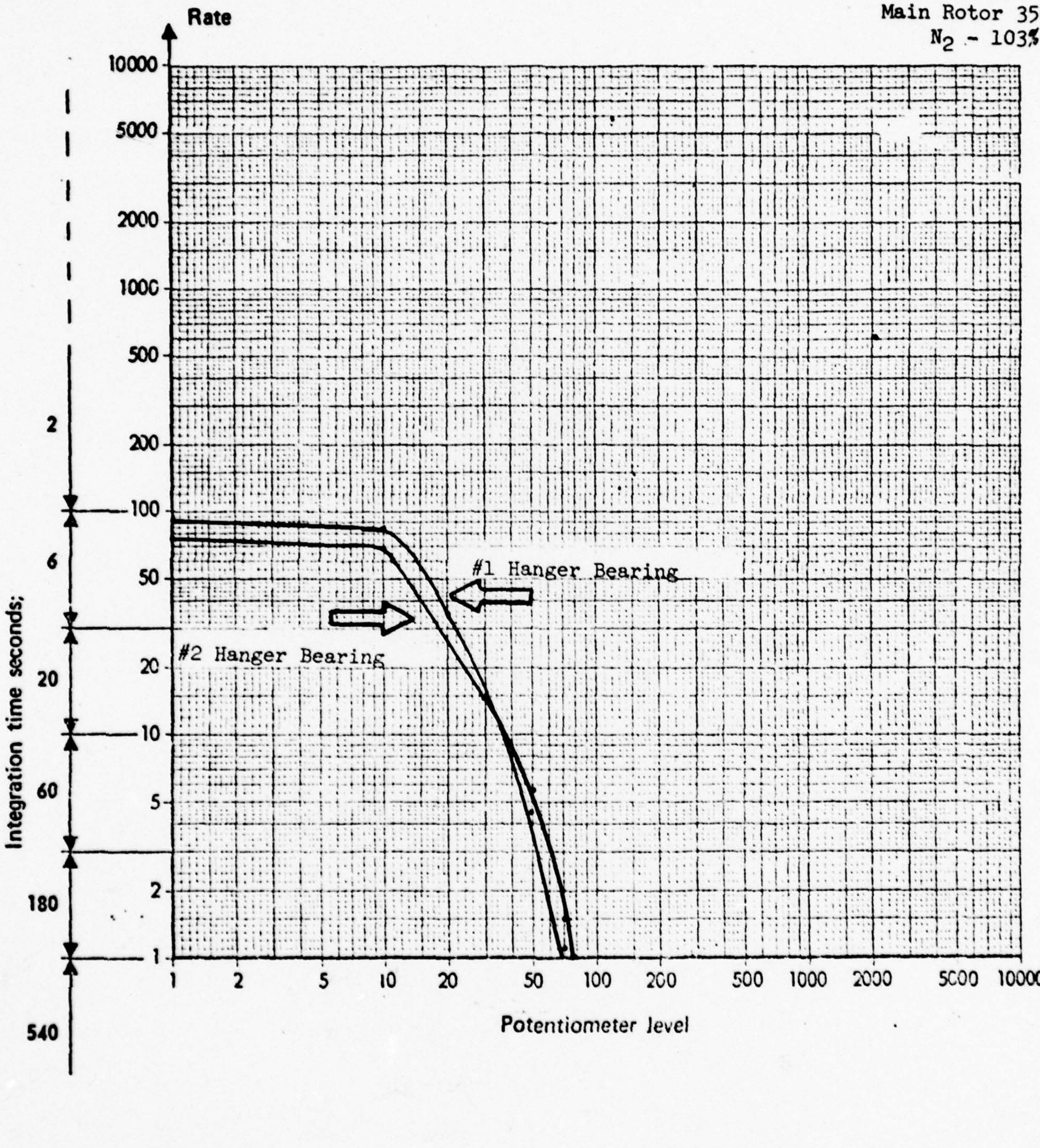


Figure 21

45

AVSCOM FLIGHT DETACHMENT
St. Louis International Airport

18 Sep 74

Hanger Bearings

OH-58A
A/C# 72-21418
T/R 6180 RPM
Main Rotor 350 RPM
N_2 - 103%

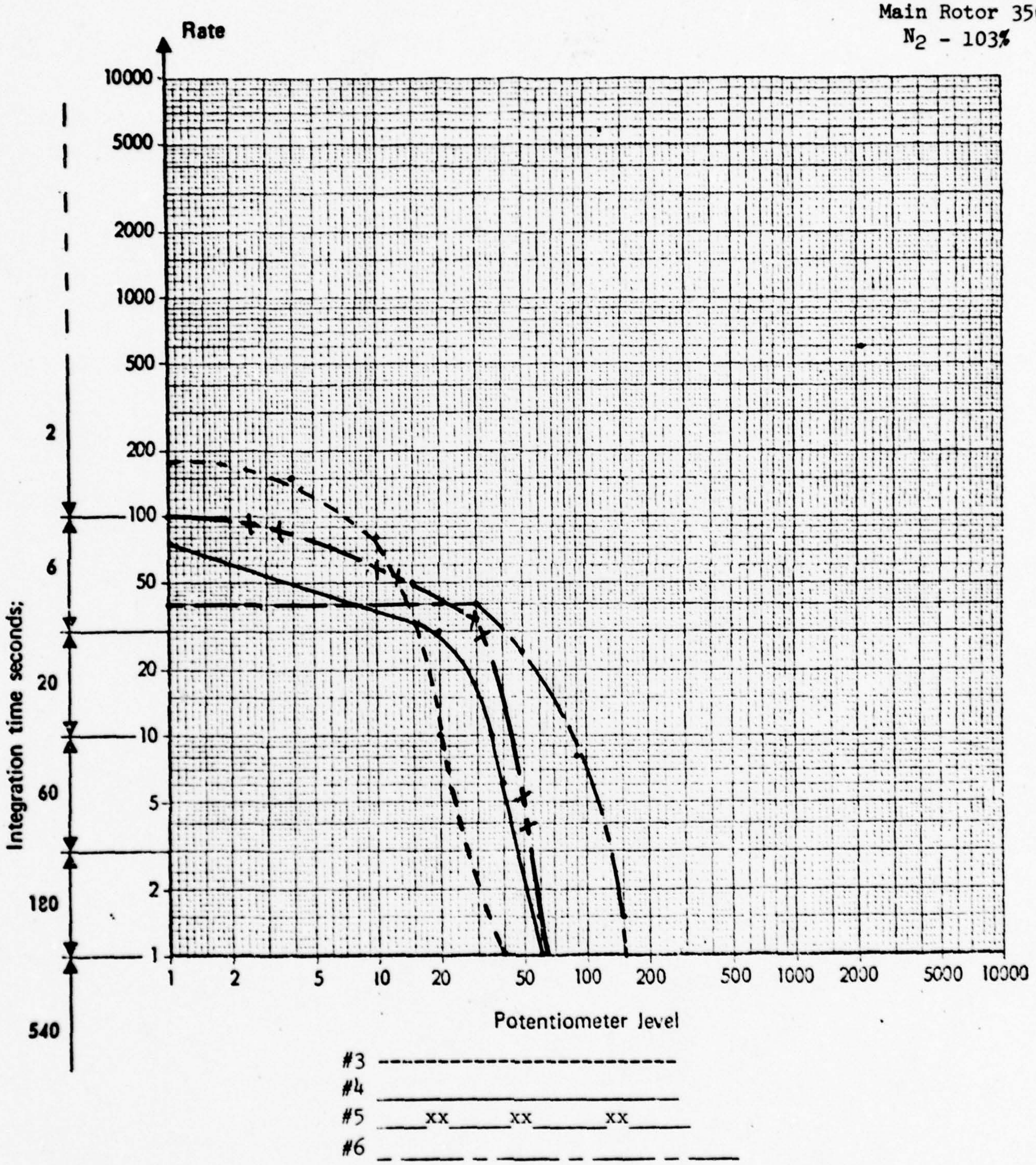


Figure 22

AVSCOM FLIGHT DETACHMENT

ST. LOUIS INTERNATIONAL AIRPORT

18 Sep 74

90^{o} Gear Box

OH-58A
A/C# 72-21418
T/R 6180 RPM
Main Rotor 350 RPM
N_2 - 103%

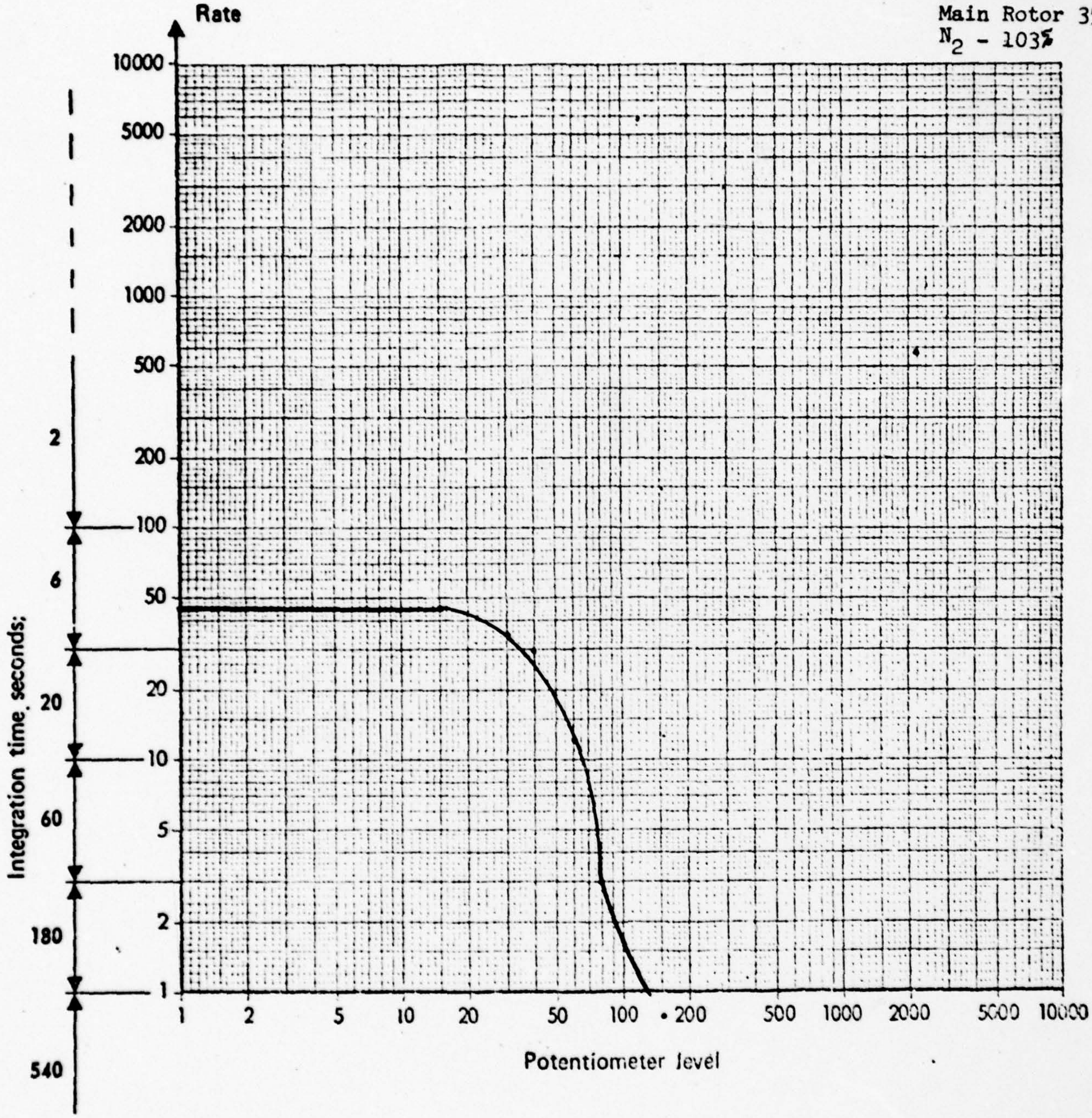
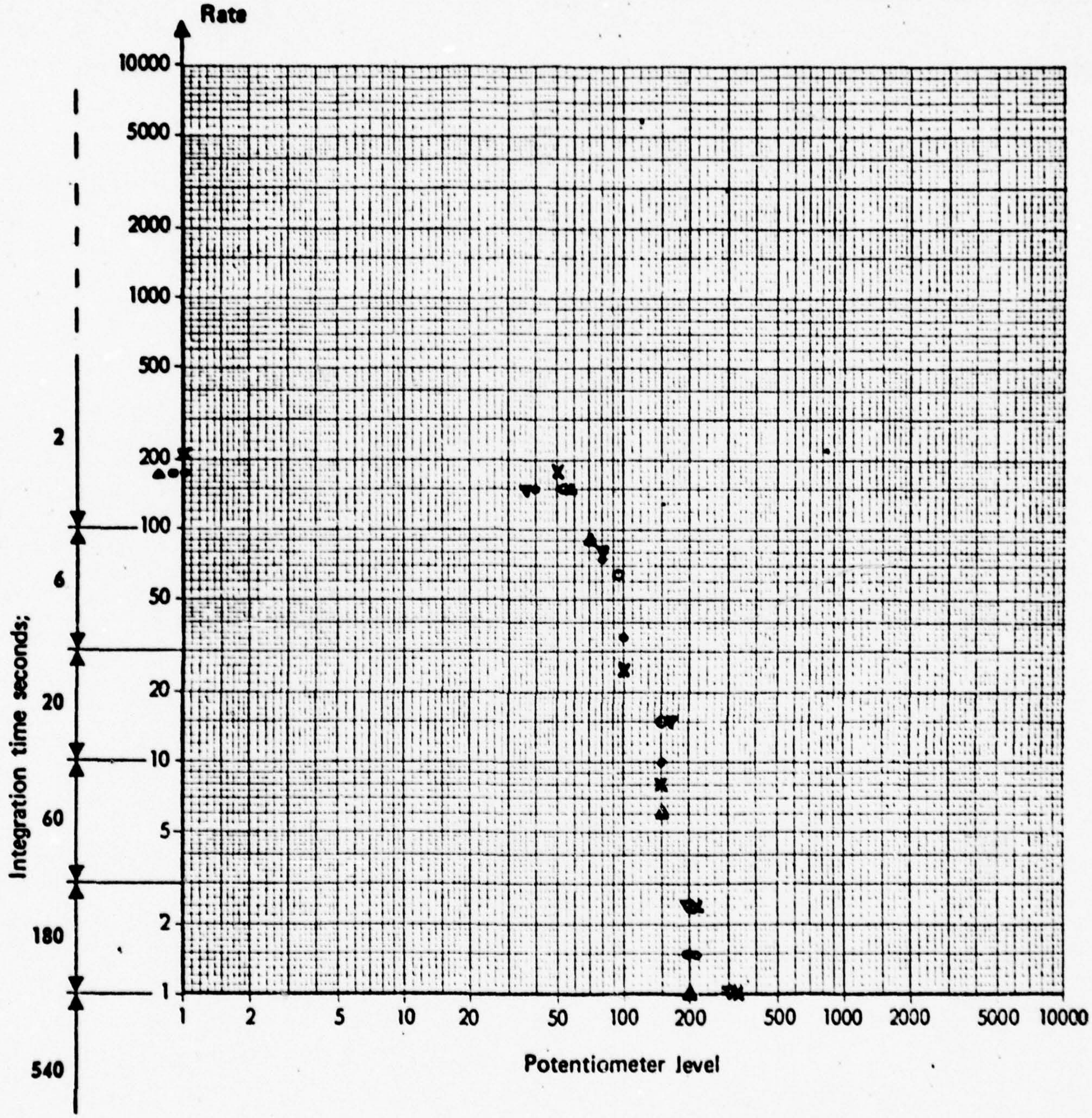


Figure 23

2.6 FLIGHT DATA

Although not a contractual requirement, data was collected with the shock pulse meter under conditions other than ground runs. Figure 24 shows a comparison of ground, hover-in-ground effect, low and high speed flight, and autorotation conditions. The data was collected with an accelerometer mounted on the input drive quill on UH-1H 69-15550. Figure 25 compares two UH-1H helicopters, both at the same high-speed flight condition. At least as far as the input drive quill is concerned, the various flight conditions had a negligible influence on the shape of the shock emission envelope or on the rate or level readings. The shock emission envelopes fall quite well within the scatter of the bulk of the readings shown in Figure 16. More information will be required before advancing any conclusions as to optimum sensor location or flight profile to record shock pulse signature.

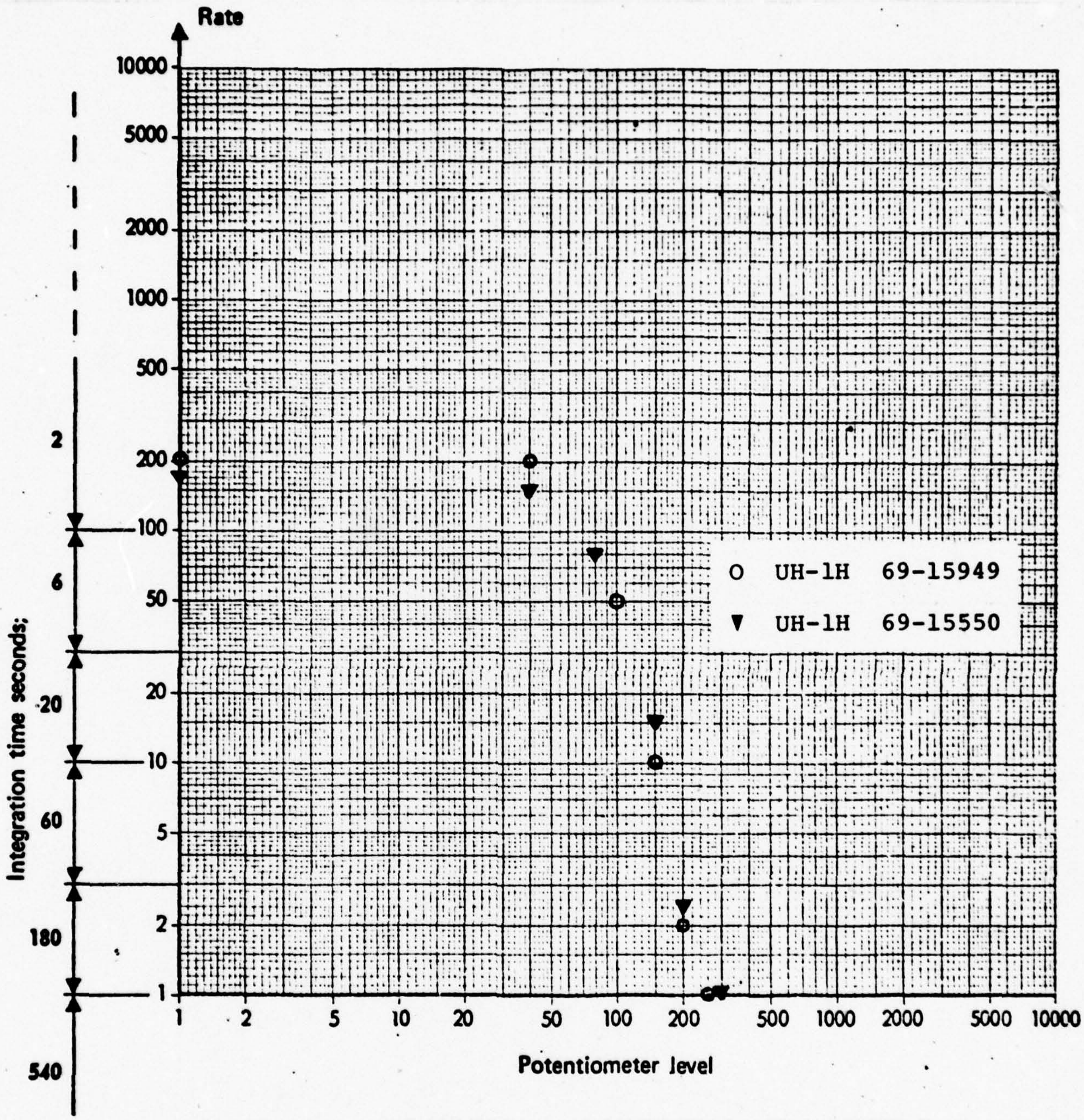


Comparison of Flight and Ground Data
Input Drive Quill, UH-1H S/N 69-15550

		Airspeed (KTS)	Torque (PSI)	N_1 (%)
.	Ground IGE	-	10	86
o	Hover 16E	-	25	91.8
Δ	Low Speed	75	18	90
∇	High Speed	110	31	91
x	Autorotation	80	0	72

N_2 = 6600 Alt 3000'

Figure 24



--- Test Conditions

Airspeed 110 KTS
Altitude 3000 ft
N_2 = 6600 RPM
Torque 31 psi

Figure 25

3.0 GEAR CONDITION TESTS

A feasibility study for extending the shock pulse technique to detecting damaged gears in a UH-1 42° gearbox was subcontracted to SKF Industries, King of Prussia, Pennsylvania. The College provided three 42° gearboxes and installed the damaged gears for test purposes. The 42° gearboxes were operated in a test fixture described in Appendix 3.1. Initial tests of comparison of shock emission curves of heavily damaged gears compared to baseline (or undamaged) data were inconclusive. The test fixture was then redesigned to transmit higher loads. However, no appreciable differences in shock levels were seen except for one transient event. No substantial changes were noted when a second set of damaged gears was installed.

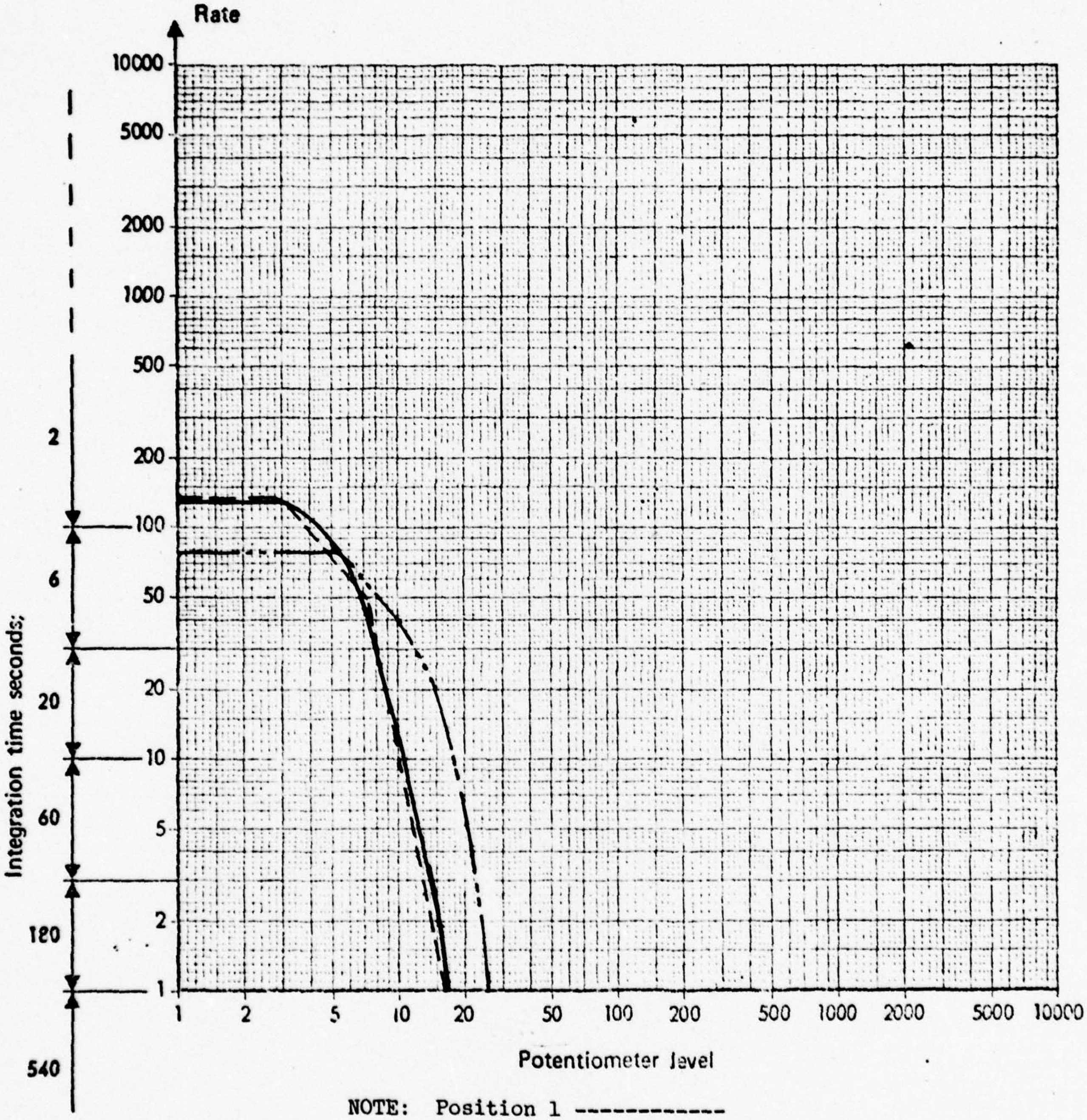
Tests involving a second 42° gearbox with a artificially damaged output quill did not yield repetitive results. Position 1 data, for instance, indicated a high rate of shocks at low shock levels for an implanted gear at low rpm but did not appear at higher rpm. Data from the addition of a damaged input quill unfortunately could not be directly compared as the SKF report did not give the necessary horsepower information. (This will be clarified for the final report.) However, fluctuations were noted in the shock rate data which were of similar nature to that of degraded gearboxes on installed operational helicopters. SKF infers that the fluctuations are due to particulate contaminant in the lubricant and therefore the faulty gear is detected in a secondary manner. Unfortunately when the test data is taken as a whole, this infererence appears ambitious.

The standard attachment fixture designed by the College was utilized in the final tests and compared to the "optimized" SKF sensor location. The sensor was attached to a bolt on the input quill housing as in its normal use. Inasmuch as flucturations were noted in the shock pulse curves, mean values were plotted for the two SKF positions and the Parks attachment. Data was taken from Figures 24-29 of Appendix 3.1 and are replotted and compared in Figures 26 and 27. It does not appear that the optimized SKF location is any more sensitive to the degraded gears or bearings than the Parks attachment. Indeed, for the damaged gear, the SKF position 1 location is nearly identical in reading to that of the Parks attachment.

Mean Profiles- Damaged Gears

42° Gear Box

SN B13-1561



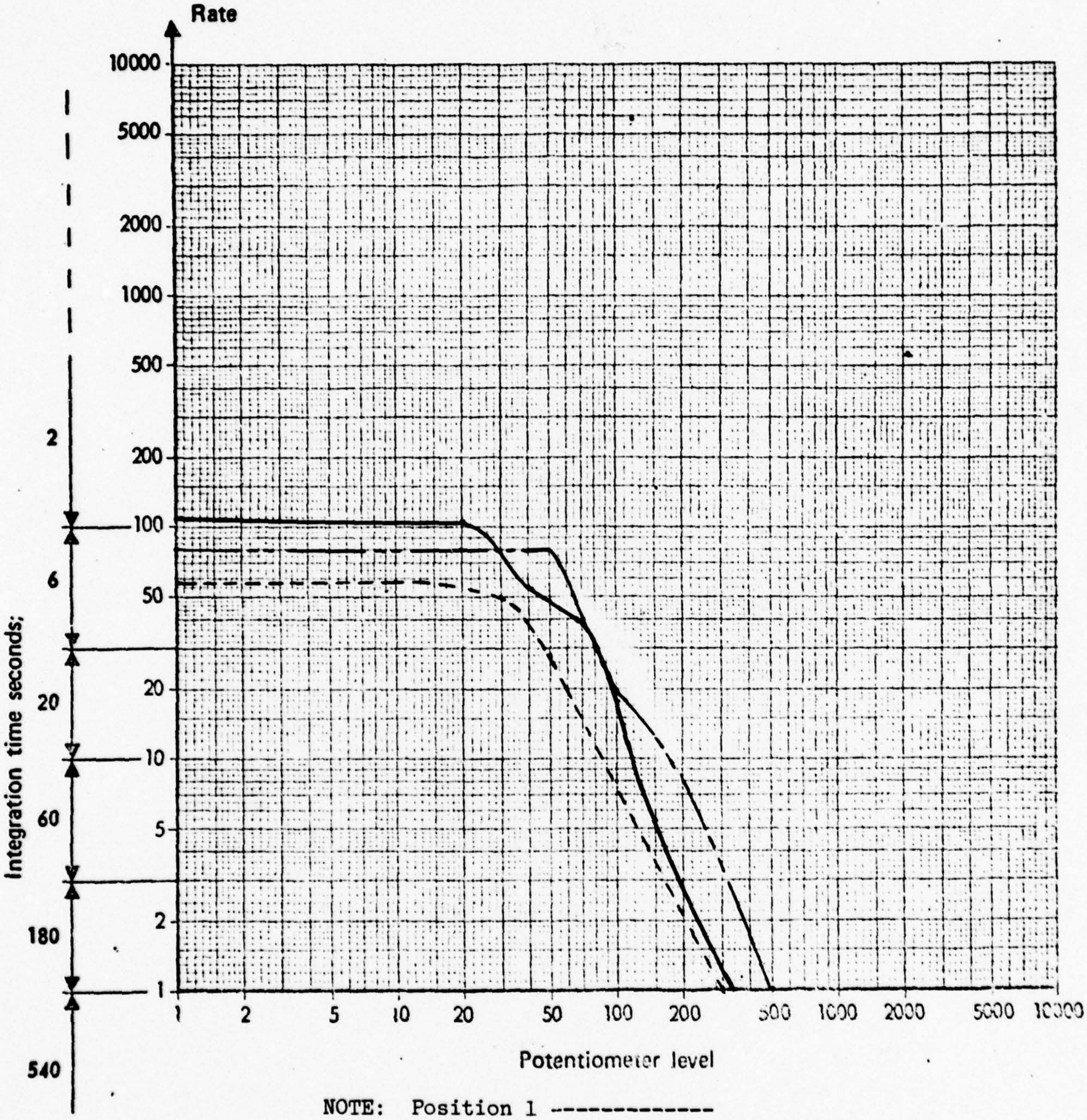
NOTE: Position 1 ------------
Position 2 ______ _ _ ______ _ _ ______
Parks designed attachment________________

Figure 26

Mean Profiles - Damaged Bearing

42^o Gear Box

SN B13-1561



NOTE: Position 1 -------------

Position 2 _____ _ _ ________ _ _ ________

Parks designed attachment_______________

Figure 27

54

4.0 CONCLUSIONS AND RECOMMENDATIONS

The results of specific teardown information to shock pulse signatures of the various components can be found with the assemblies removed for analysis. Damage found in multiple bearing assemblies such as the 90° and 42° gear box cannot be correlated to shock pulse data of an individual bearing assembly within the gear box. The MEPA 10A with present accelerometer mounting techniques will not allow for specific discrimination as to exact type and location of defect. Present use of the MEPA 10A does, however, allow it to be an effective diagnostic tool to determine over all assembly condition. It is felt the shock pulse technique has proven its effectiveness as a diagnostic tool in discriminating between assemblies with no defects and those with various stages of degradation. It is a fast and reliable procedure to determine general assembly health and when coupled with sufficient baseline data of a particular component it can track damage progress and provide the input for making a prognosis of the elements functional life.

In-so-far as the 42° gear box test cell use of the MEPA 10A for gear damage detection, it is felt the accelerometer attachment using the VD-2 provided data of equal value to any other methods. A more indepth look at the specific input from SKF Industries will be required before forming any conclusions as to this effort in attesting usable shock pulse data from damaged gears.

In light of the results obtained in demonstrationg the effectiveness of the shock pulse technique in revealing bearing damage, the following represents recommendations for future actions:

1) Initiate a program to secure shock pulse data from aircraft in flight profiles to establish the shock emission signatures

of components under different load situations. A flight program should undertake the task of determining the consistency and reliability of obtaining data at several different flight conditions to refine as much as possible the optimum recording of a component's condition.

2) Establish through further data collection, general operating limitations of the desirable shock pulse envelope of Rate vs Level on bearing and gear components.

3) Undertake an engineering effort aimed at the refinement of accelerometer attachment with emphasis toward flight worthy installations.

4) The mast bearing and input drive quill of aircraft 66-15071 a UH-1C helicopter belonging to the 281st Aviation Company at Bi-State Airport showed shock emissions profiles which necessitate collateral teardown information. Since both components were parts of the transmission assembly of the helicopter, there is a likelihood that a defect may be present in the assembly, teardown information would be needed to confirm this supposition.

5) Two 90^{o} gear boxes other than the one assembly removed for teardown, yielded shock profiles which we feel were in excess of a normal profile and also should be removed for teardown.

Due to the lack of replacement assemblies at this time, we were unable to remove these. The summary graph showing data scatter in this report will reveal the irregularities of these assemblies.

5.0 TABLES AND APPENDIXES

58

TABLE 2.1

Aircraft #				Hours					
#	Type	Position	Serial #	TSN	TSO	Comment	Date	Rate	Level
38784	UH1H	Mast Bearing	UNK			Portside Position	21 May 74	90	70
38784	UH1H	#3 hanger bearing	A20-36705 damaged			6600	21 May 74	150	1500
38784	UH1H	#3 hanger bearing	A20-36705 damaged			4600	21 May 74	80	1000
38784	UH1H	Input Drive Quill					21 May 74	90	200
38484	UH1H	#4 hanger bearing				4600	21 May 74	225	4800
38784	UH1H	#4 hanger bearing	A20-31435			6600	21 May 74	225	7000
38784	UH1H	Mast Bearing				Front Position	23 May 74	65	70
38784	UH1H	Mast Bearing				Starboard Position	23 May 74	95	60
38784	UH1H	Mast Bearing				AFT Position	23 May 74	90	150
BC14	UH1H	#3 hanger bearing				Left Pedal	13 Jun 74	35	65
BC14	UH1H	#4 hanger bearing				Left Pedal	13 Jun 74	300	1000
BC14	UH1H	#4 hanger bearing				Right Pedal	13 Jun 74	300	1000
BC14	UH1H	#4 hanger bearing				Neutral Pedal	13 Jun 74	300	700
BC13	UH1H	#4 hanger bearing	A20-34779				13 Jun 74	120	100
BC13	UH1H	#3 hanger bearing					13 Jun 74	45	150
BC14	UH1H	#4 hanger bearing				Flight Idle	13 Jun 74	220	200
BC14	UH1H	42° Gear Box	B13-9881			Data Scatter 3 Runs	13 Jun 74	140/190	100/160
BC14	UH1H	#4 hanger bearing				6400 Full Rt.Pedal	13 Jun 74	240	900
BC14	UH1H	#3 hanger bearing				Flight Idle	13 Jun 74	150	25
BC13	UH1H	#3 hanger bearing				6400 Full Rt.Pedal	13 Jun 74	90	50
BC13	UH1H	42° Gear Box	B13-4312				13 Jun 74	75	50

Aircraft #		Position	Serial #	Hours		Comment	Date	Rate	Level
#	Type			TSN	TSO				
BC13	UH1H	Hanger Bearing					14 Jun 74	100	50
BC13	UH1H	42^{o} Gear Box	B13-8282				14 Jun 74	200	700
BC13	UH1H	Input Drive Quill	ABU-11067				14 Jun 74	150	150
BC14	UH1H	42^{o} Gear Box					14 Jun 74	200	70
BC13	UH1H	#3 hanger bearing					14 Jun 74	65	150
BC13	UH1H	Mast Bearing					14 Jun 74	160	55
BC14	UH1H	42^{o} Gear Box					14 Jun 74	25	80
BC14	UH1H	42^{o} Gear Box					14 Jun 74	175	30
15550	UH1H	42^{o} Gear Box Output	B13-2929	1324	New		30 Jul 74	25	80
15550	UH1H	42^{o} Gear Box Input	B13-2929	1324	New		30 Jul 74	100	90
15550	UH1H	90^{o} Gear Box	ABC-5688	0	188	Progressing Damage	30 Jul 74	150	650
13740	UH1H	90^{o} Gear Box	B13-8168	106	0		31 Jul 74	100	70
13740	UH1H	42^{o} Gear Box Output	A13-1097	173	0		31 Jul 74	75	60
13740	UH1H	42^{o} Gear Box Input	A13-1097	173	0		31 Jul 74	75	60
13740	UH1H	#3 hanger bearing					31 Jul 74	120	60
13740	UH1H	#4 hanger bearing					31 Jul 74	140	30
60529	UH1H	42^{o} Gear Box Output	A13-1639	75	0		1 Aug 74	350	320
60529	UH1M	42^{o} Gear Box Input	A13-1639	75	0		1 Aug 74	35	75
60529	UH1M	90^{o} Gear Box	ABC-2892	75	0		1 Aug 74	600	70
15200	UH1M	42^{o} Gear Box Output	B138818	24	0		1 Aug 74	150	30
15200	UH1M	42^{o} Gear Box Input	B138818	24	0		1 Aug 74	40	80

Aircraft #				Hours					
#	Type	Position	Serial #	TSN	TSO	Comment	Date	Rate	Level
15200	UH1M	90° Gear Box	A 133069	10	0		1 Aug 74	100	55
60529	UH1M	#3 hanger bearing	A 2064529	75	0		1 Aug 74	400	800
60529	UH1M	#2 hanger bearing	A 2052529		0		1 Aug 74	250	80
60529	UH1M	Mast Bearing	574D	UKN	N/A		1 Aug 74	75	50
15200	UH1M	#3 hanger bearing			167		1 Aug 74	130	50
15200	UH1M	#2 hanger bearing			167		1 Aug 74	300	80
15200	UH1M	#1 hanger bearing			167		1 Aug 74	340	160
59884	UH1D	90° Gear Box	B13-5077		626		5 Aug 74	70	95
59884	UH1D	42° Gear Box Input	B13-9384		626		5 Aug 74	25	80
59884	UH1D	#3 hanger bearing	A20-43493				5 Aug 74	150	20
60630	UH1C	42° Gear Box Output	B13-3234		219		6 Aug 74	625	300
60630	UH1C	42° Gear Box Input	B13-3234		219		6 Aug 74	100	40
60630	UH1C	90° Gear Box	B13-9937		12		6 Aug 74	95	40
60630	UH1C	Input Drive Quill					6 Aug 74	150	100
60630	UH1C	#1 hanger bearing					6 Aug 74	300	70
15071	UH1C	Input Drive Quill					6 Aug 74	400	1100
15071	UH1C	#3 hanger bearing					6 Aug 74	320	850
15071	UH1C	42° Gear Box Input					6 Aug 74	85	50
60630	UH1C	Mast Bearing	8221:	1686			6 Aug 74	55	80
60630	UH1C	#3 hanger bearing					6 Aug 74	160	150
60630	UH1C	#2 hanger bearing					6 Aug 74	100	40

Aircraft #		Position	Serial #	Hours		Comment	Date	Rate	Level
#	Type			TSN	TSO				
5071	UH1C	#2 hanger bearing	A20-15990		237		6 Aug 74	300	3000
5071	UH1C	42° Gear Box Output	BBB-1894		237		6 Aug 74	80	80
5071	UH1C	90° Gear Box	B13-3307		6		6 Aug 74	150	30
5071	UH1C	Mast Bearing	613-N	1260			6 Aug 74	450	1000
5071	UH1C	#1 hanger bearing	A20-66943		237		6 Aug 74	65	50
9771	UH1H	Input Drive Quill					7 Aug 74	90	100
9771	UH1H	Mast Bearing	7377A				7 Aug 74	75	40
9519	UH1M	Mast Bearing	MRC 3192				8 Aug 74	25	50
9519	UH1M	Input Drive Quill					8 Aug 74	150	200
9519	UH1M	#2 hanger bearing	A20-57910		171		8 Aug 74	120	70
9519	UH1M	#3 hanger bearing	A20-26938		27		8 Aug 74	150	50
9519	UH1M	90° Gear Box	B13-8655		171		8 Aug 74	100	40
9519	UH1M	#1 hanger bearing			171		8 Aug 74	340	700
9519	UH1M	42° Gear Box Input	ABB-742		171		8 Aug 74	110	43
9519	UH1M	42° Gear Box Output	ABB-742		171		8 Aug 74	100	40
5091	UH1M	#1 hanger bearing					9 Aug 74	200	600
5091	UH1M	42° Gear Box Input	B13-646				9 Aug 74	30	40
16354	UH1H	Mast Bearing					12 Aug 74	150	60
16354	UH1H	Input Drive Quill					12 Aug 74	150	150
16354	UH1H	Generator Drive Gear					12 Aug 74	400	180
16354	UH1H	42° Gear Box Input					12 Aug 74	35	60

Aircraft # #	Type	Position	Serial #	Hours TSN	TSO	Comment	Date	Rate	Level
16354	UH1H	42° Gear Box Output					12 Aug 74	150	320
16354	UH1H	90° Gear Box					12 Aug 74	150	15
16779	UH1D	Mast Bearing					14 Aug 74	80	100
16779	UH1D	42° Gear Box Output					14 Aug 74	100	75
16779	UH1D	Input Drive Quill					14 Aug 74	75	120
16779	UH1D	42° Gear Box Input					14 Aug 74	10	40
16779	UH1D	90° Gear Box					14 Aug 74	70	200
01007	UH1H	Mast Bearing					16 Aug 74	17	55
01007	UH1H	Input Drive Quill					16 Aug 74	140	150
5550	UH1H	Input Drive Quill				Torque 0 psi	17 Sept 74	230	290
5550	UH1H	Input Drive Quill				Torque 10 psi	17 Sept 74	170	220
5550	UH1H	Input Drive Quill				Torque 31 psi	17 Sept 74	200	290
21418	OH58A	#6 hanger				T/R 6180	18 Sept 74	40	150
21418	OH58A	#5 hanger				T/R 6180	18 Sept 74	100	70
21418	OH58A	#4 hanger				T/R 6180	18 Sept 74	75	60
21418	OH58A	#3 hanger				T/R 6180	18 Sept 74	190	40
21418	OH58A	#2 hanger				T/R 6180	18 Sept 74	75	75
21418	OH58A	#1 Hanger				T/R 6180	18 Sept 74	90	67
21418	OH58A	90° Gear Box				T/R 6180	18 Sept 74	45	125
15949	UH1H	Input Drive Quill				Low Power	19 Sept 74	150	160
15949	UH1H	Input Drive Quill				High Power	19 Sept 74	200	270
15949	UH1H	#1 hanger bearing					23 Sept 74	250	1200

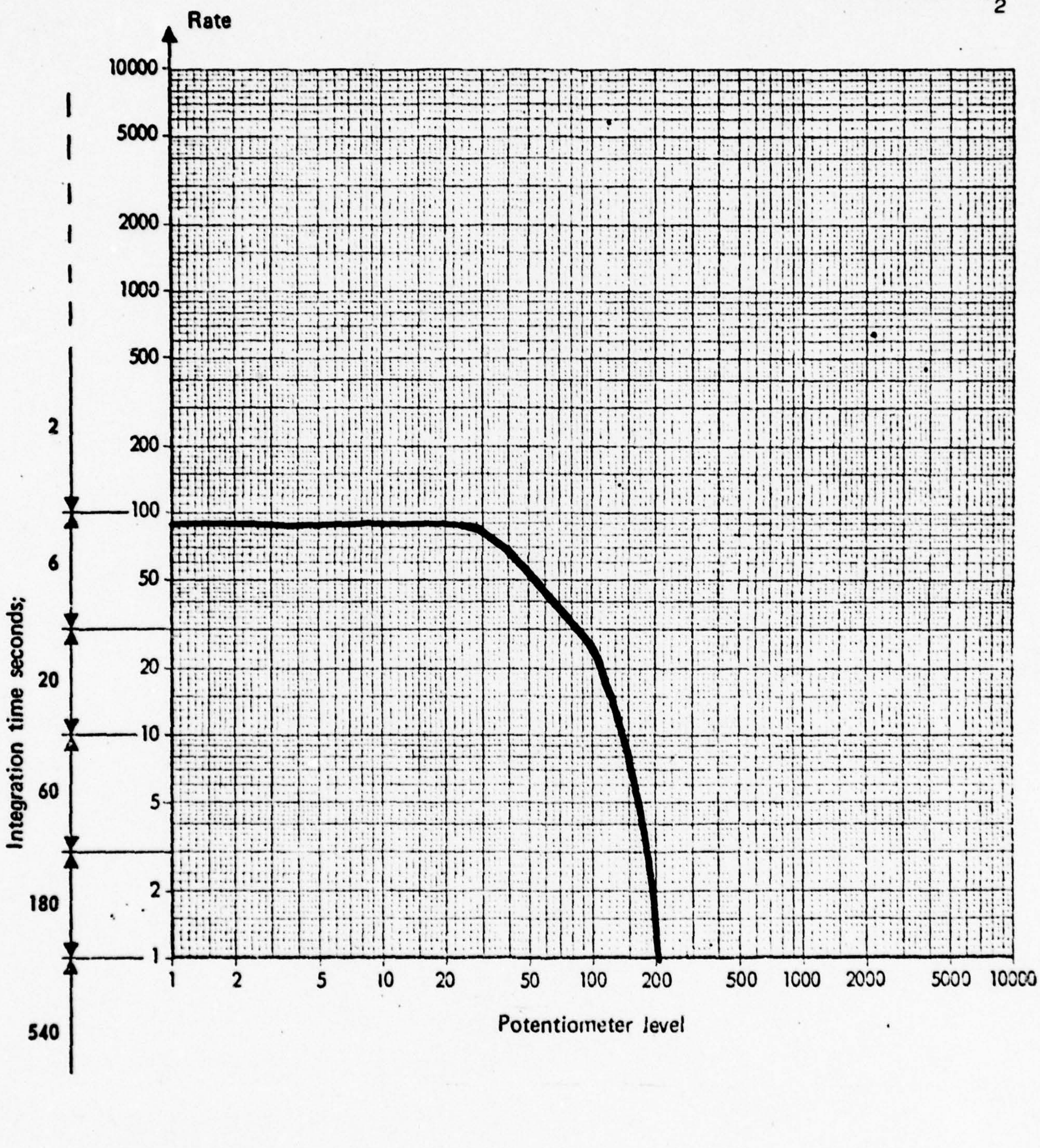
APPENDIX 2.1

63

281st Aviation Company Bi State Airport 21 May 74

Input Drive Quill

A/C 63-8784
6600 RPM N_2

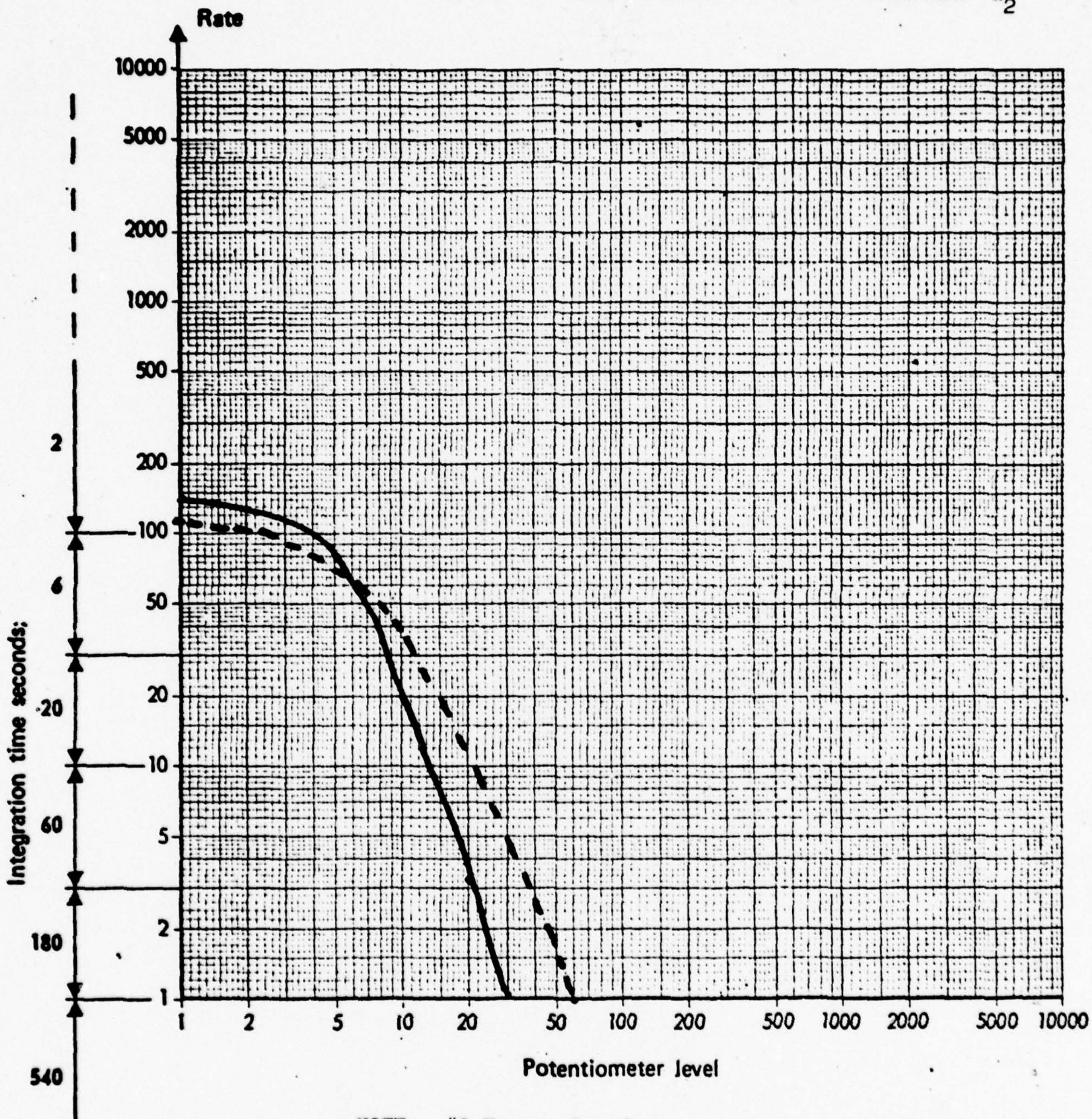


281st Aviation Company Bi State Airport 31 Jul 74

#3 Hanger Bearing

#4 Hanger Bearing

A/C 64-13740 UH-1H
6600 RPM N_2



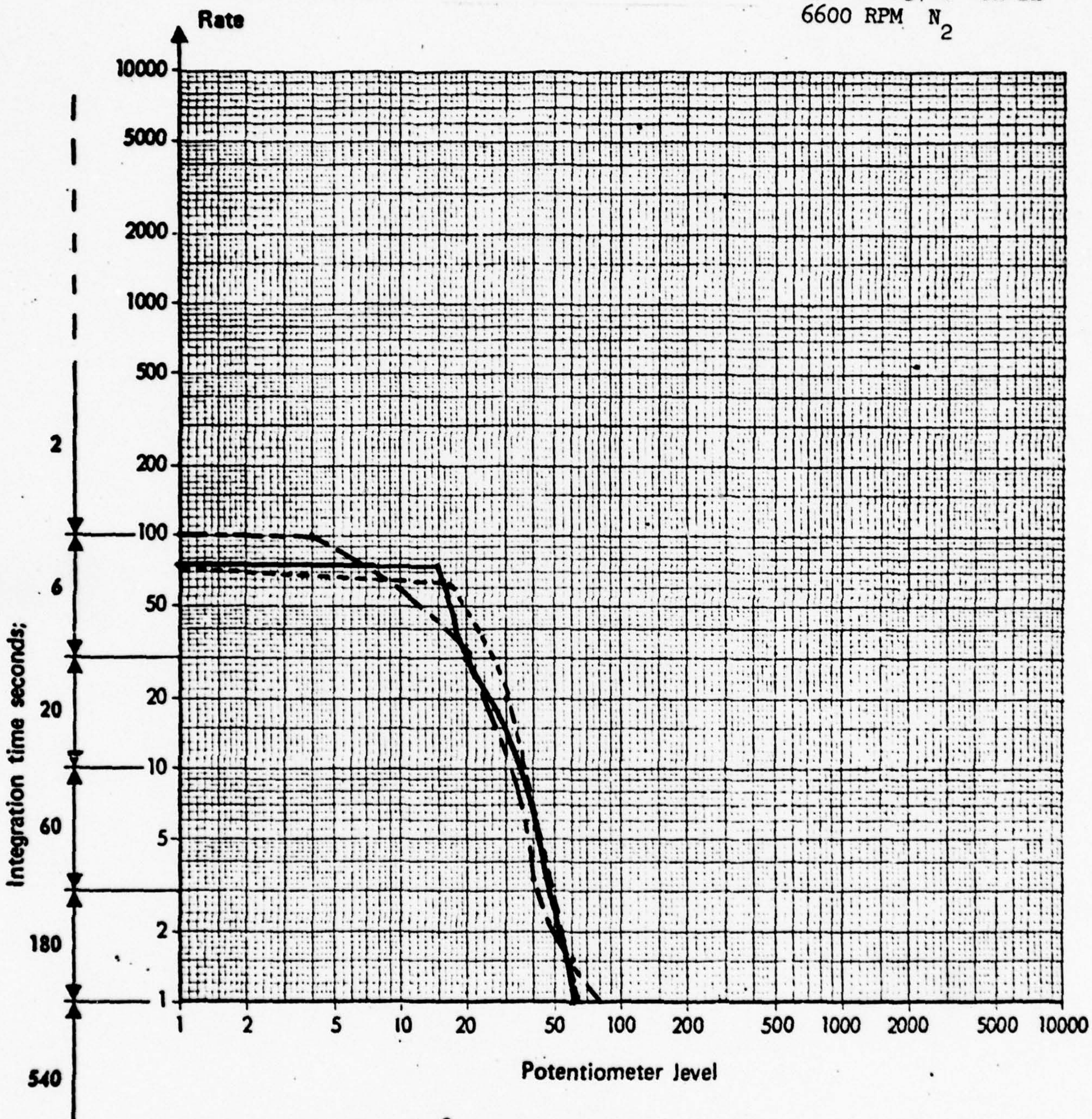
NOTE: #3 Hanger Bearing-------------

#4 Hanger Bearing_____________

281st Aviation Company Bi State Airport 31 July 1974

42° Gear Box Input
42° Gear Box Output
90° Gear Box

A/C 64-13740 UH-1H
6600 RPM N_2



NOTE: 42° Gear Box Input ______________
42° Gear Box Output--------------
90° Gear Box ____ _ ____ _ ____ _ ____

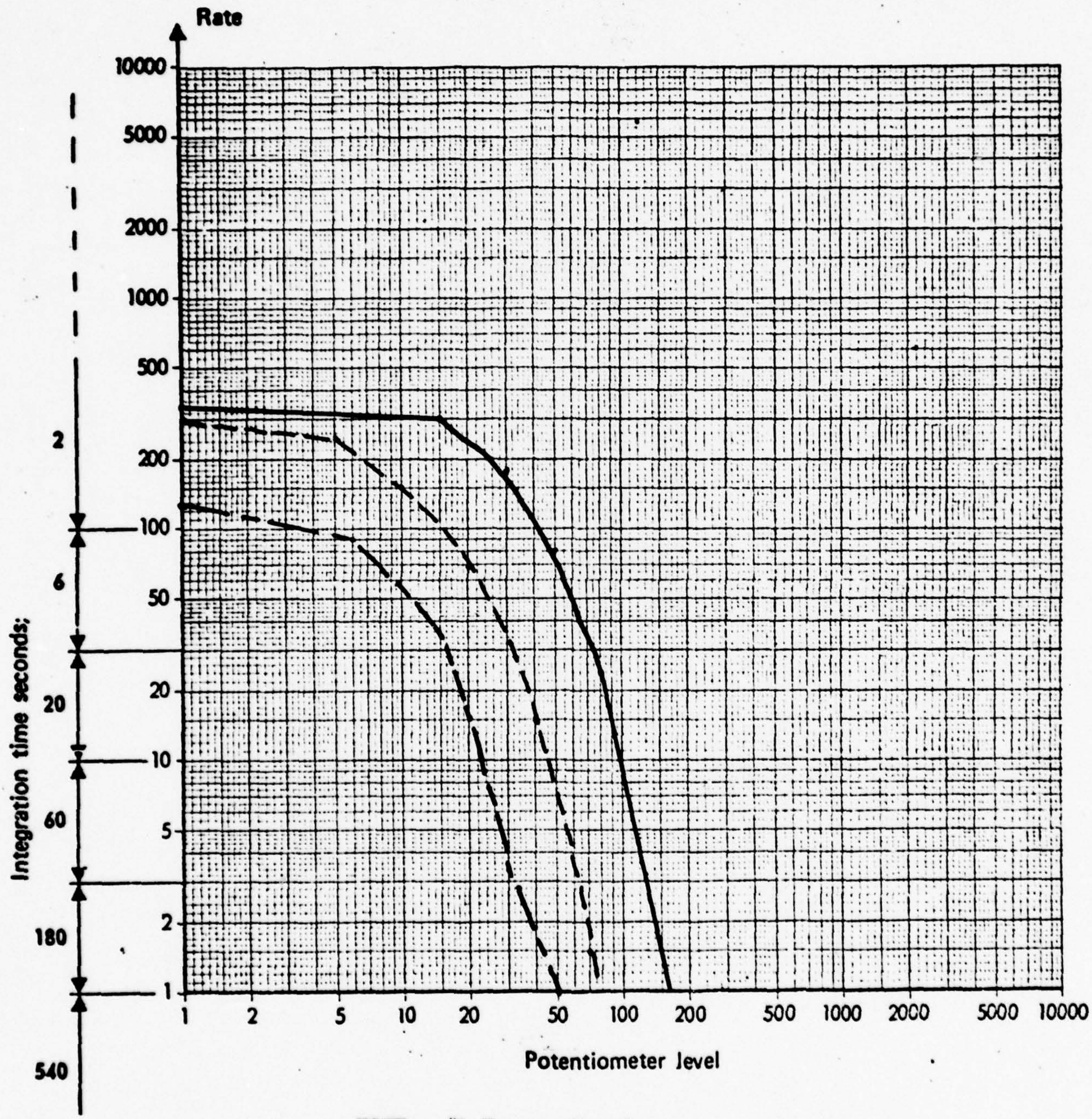
281st Aviation Company Bi State Airport 1 Aug 74

#1 Hanger Bearing

#2 Hanger Bearing

#3 Hanger Bearing

A/C 66-15200 UH-1M
6600 RPM N_2



NOTE: #1 Hanger Bearing__________________

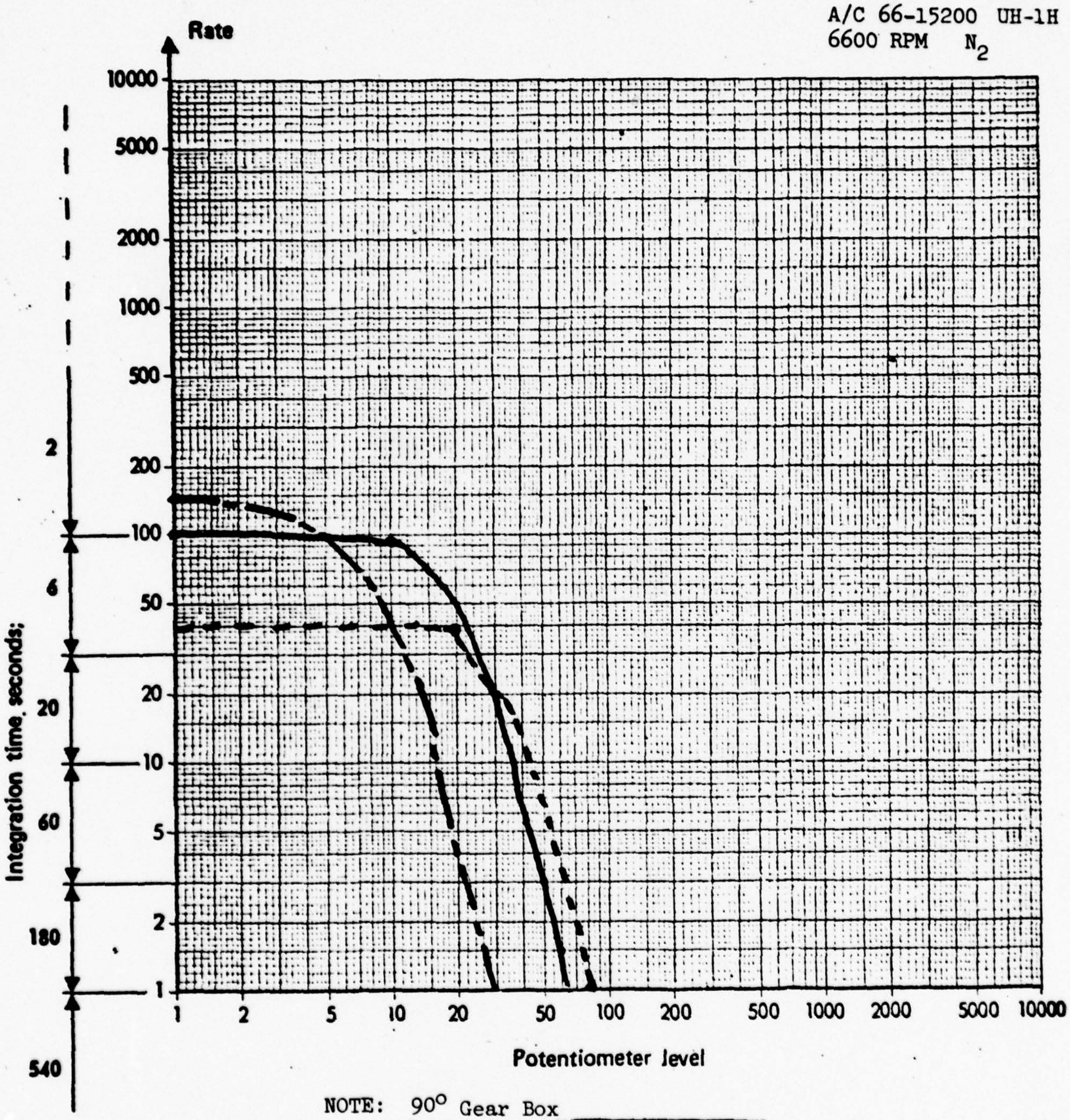
#2 Hanger Bearing------------------

#3 Hanger Bearing _____ _ _____ _ _____

281st Aviation Company Bi State Airport 1 Aug 74

90° Gear Box A 133069
42° Gear Box Input B138818
42° ~~Gear Box~~ Output

A/C 66-15200 UH-1H
6600 RPM N_2



NOTE: 90° Gear Box ____________

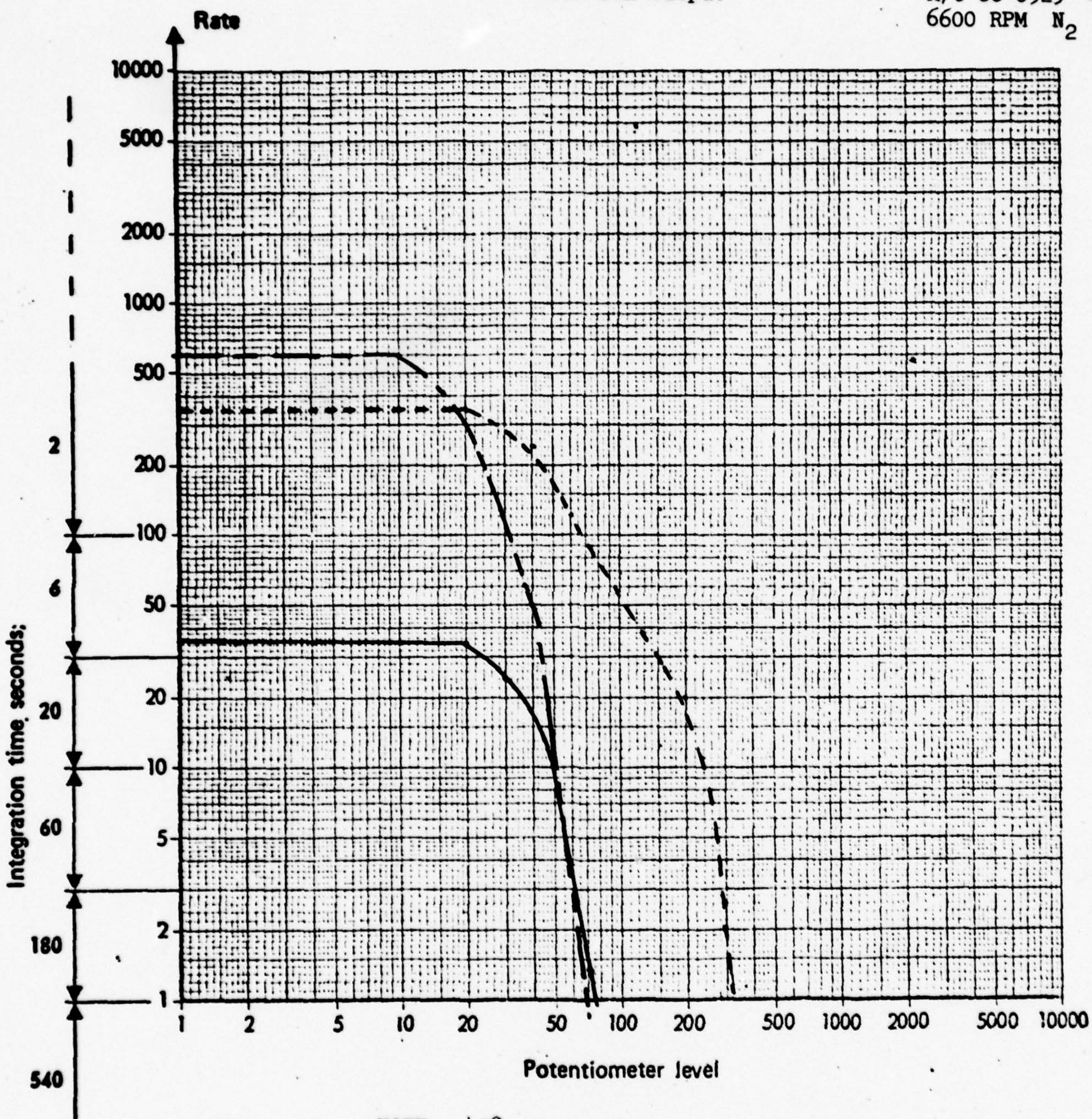
42° Gear Box Input ---------

42° Gear Box Output ___ _ ___ _ ___

281st Aviation Company Bi State Airport 1 Aug 74

42°	Gear Box Input	A131639
90°	Gear Box	ABC 2892
42°	Gear Box Output	

A/C 66-0529 UH-1M
6600 RPM N_2



NOTE: 42° G/B Input ______________

90° G/B _____ _ _____ _ _____

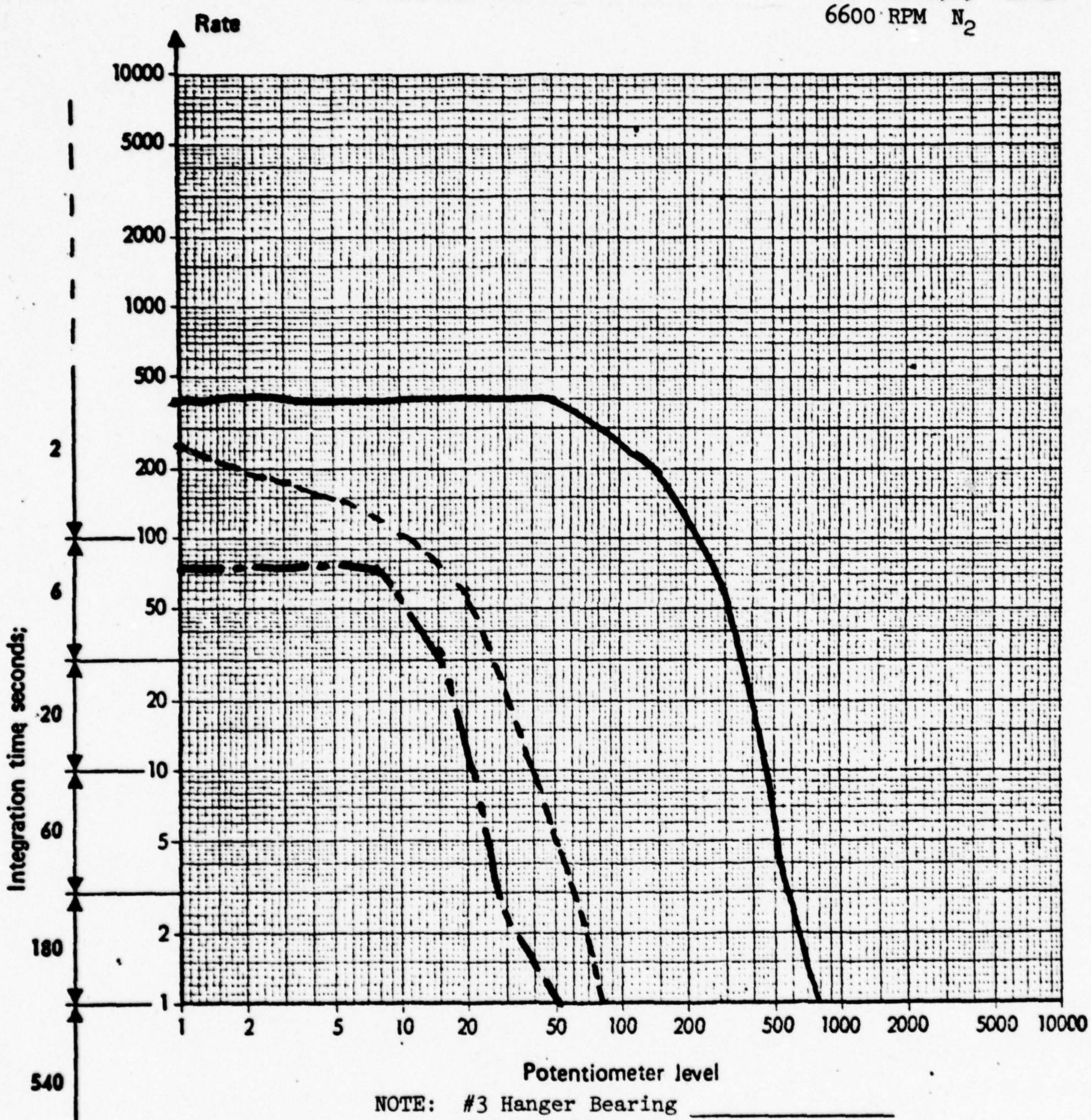
42° G/B Output --------------------

69

281st Aviation Company Bi State Airport 1 Aug 74

#3 Hanger Bearing A 2064529
#2 Hanger Bearing A 2052529
Mast Bearing

A/C 66-0529 UH-1M
6600 RPM N_2



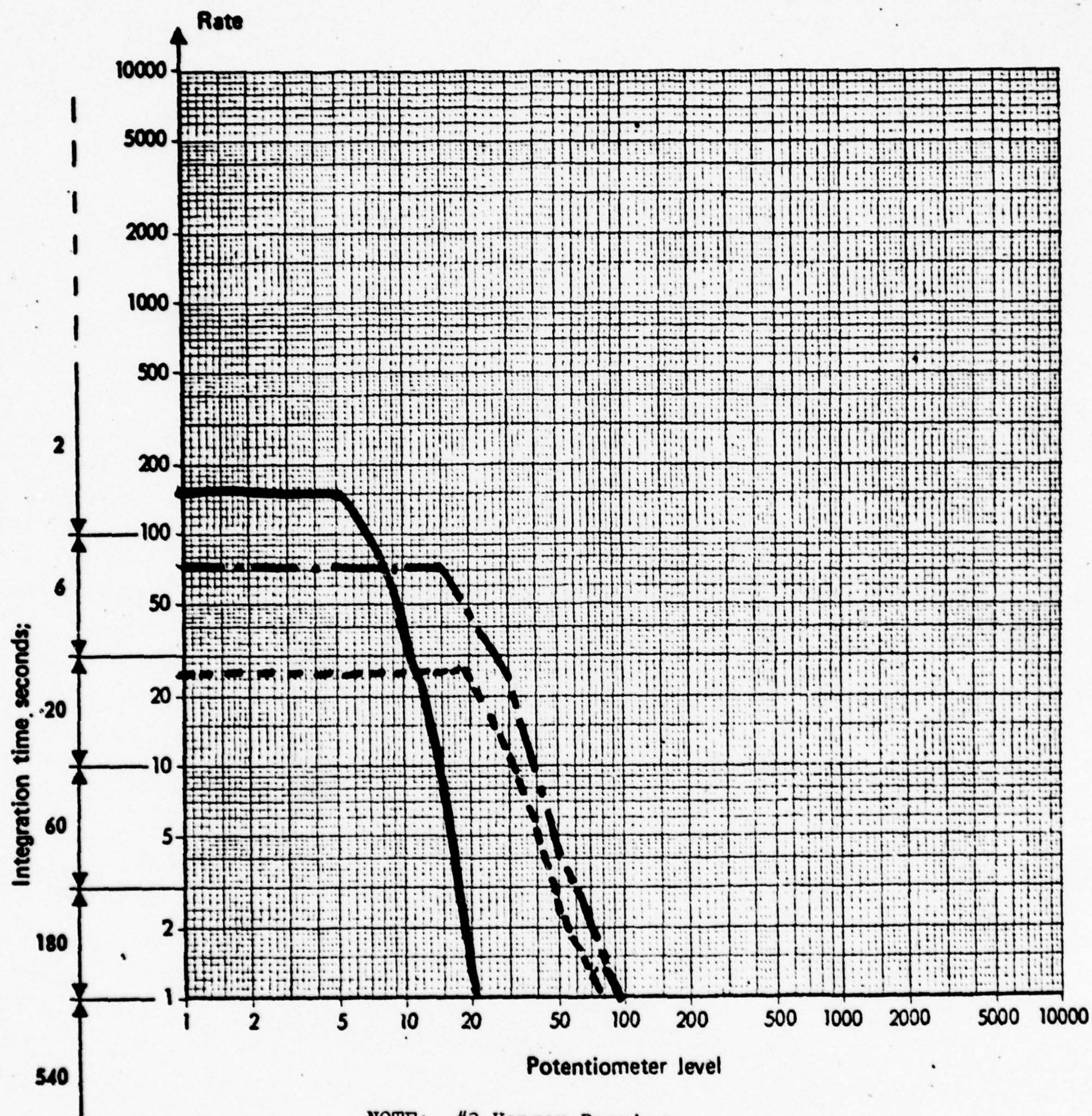
NOTE: #3 Hanger Bearing ________________

#2 Hanger Bearing ----------------

Mast Bearing ____ - ____ - ____ - ____

281st Aviation Company Bi State Airport 5 Aug 1974
#3 Hanger Bearing A20-43493
42^{o} Gear Box Input B13-9384
90^{o} Gear Box B13-5077

A/C 65-9884 UH-1D
6600 RPM N_2



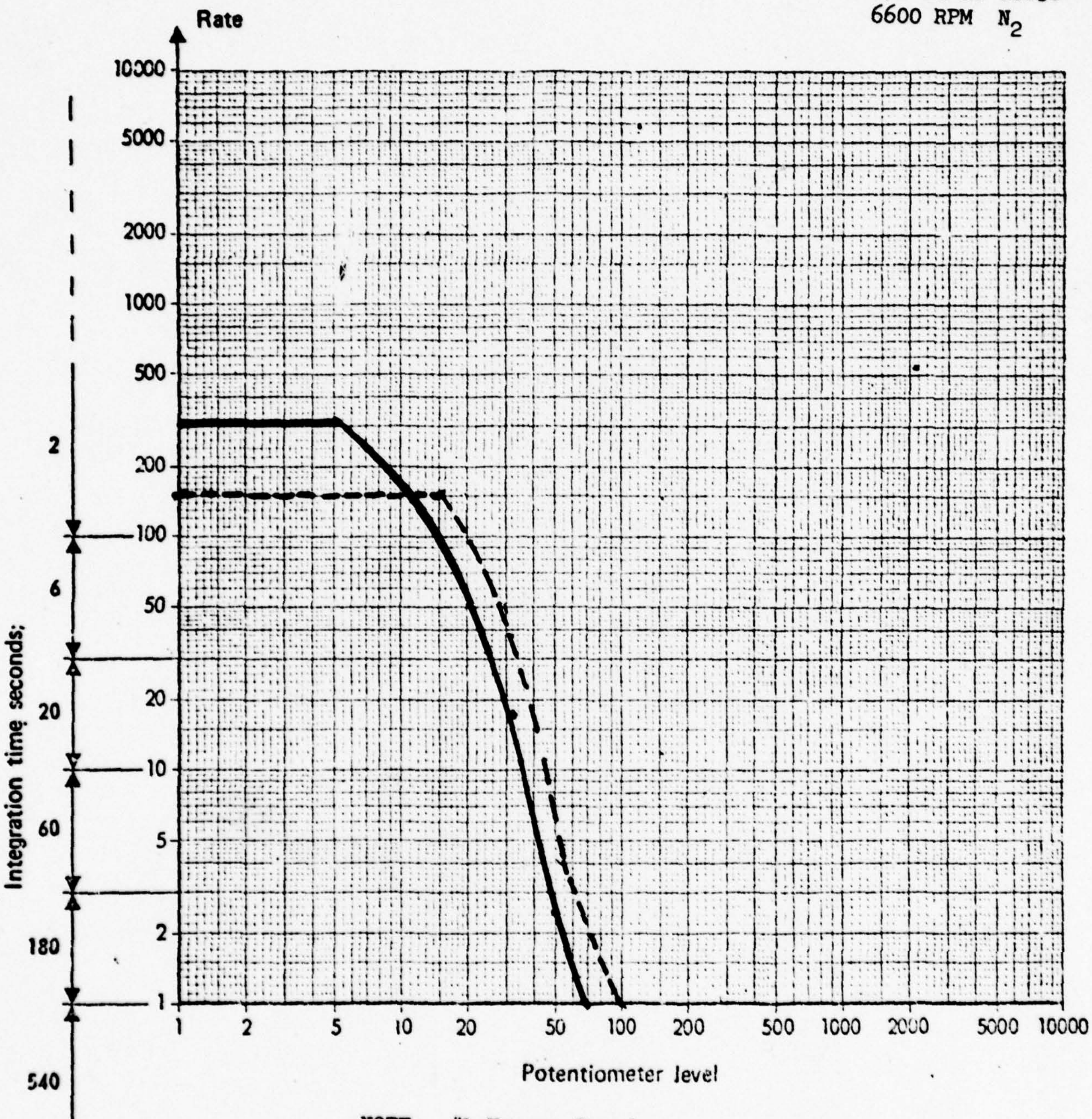
NOTE: #3 Hanger Bearing ________________
42^{o} Gear Box Input --------------
90^{o} Gear Box _____ _ _____ _ _____

281st Aviation Company Bi State Airport 6 Aug 74

#1 Hanger Bearing

Input Drive Quill

A/C UH-1C 60630
6600 RPM N_2



NOTE: #1 Hanger Bearing ________________

Drive Quill --------------------

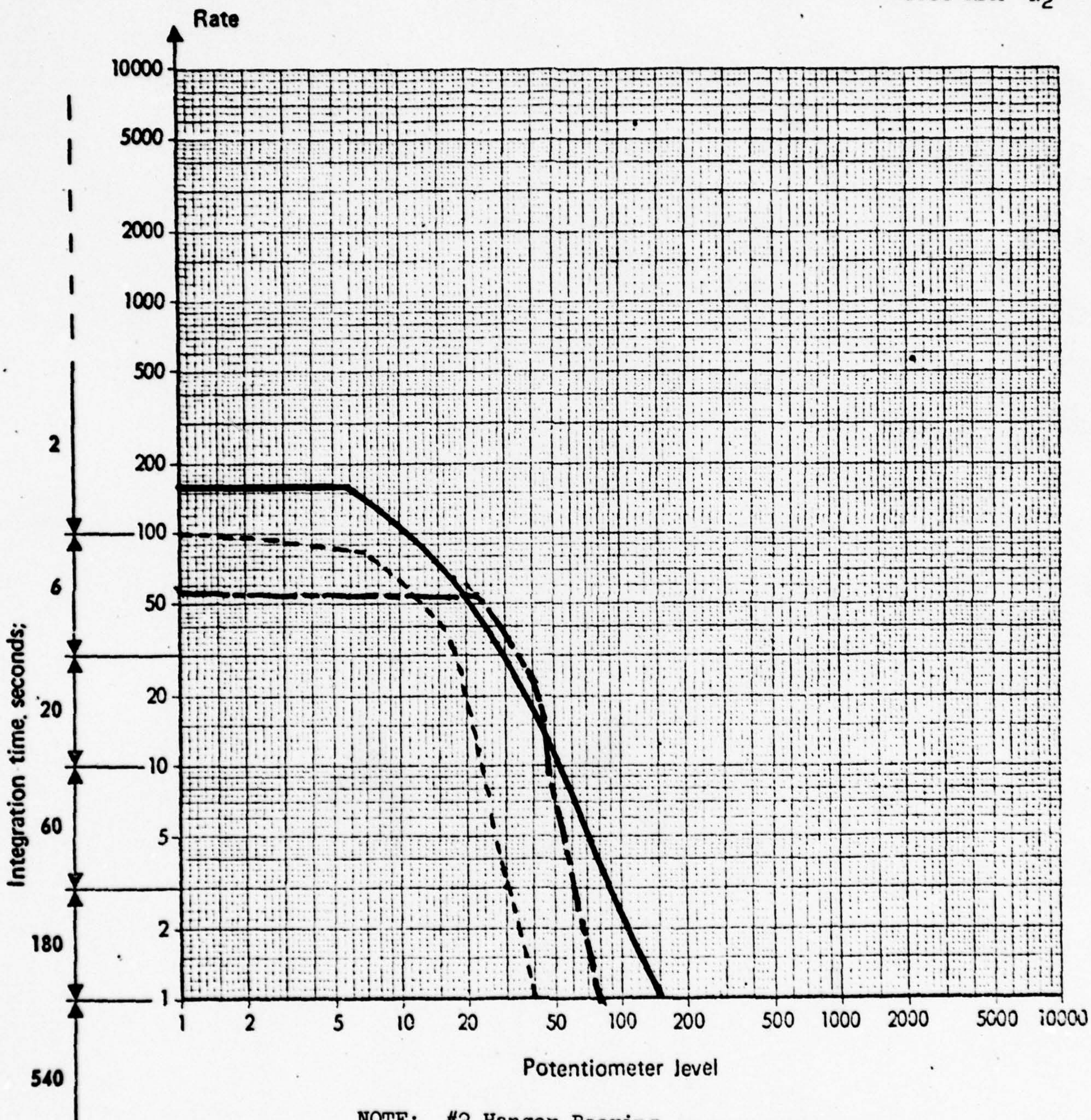
281st Aviation Company Bi State Airport 6 Aug 74

#2 Hanger Bearing

#3 Hanger Bearing

Mast Bearing

A/C UH-1C 60630
6600 RPM N_2

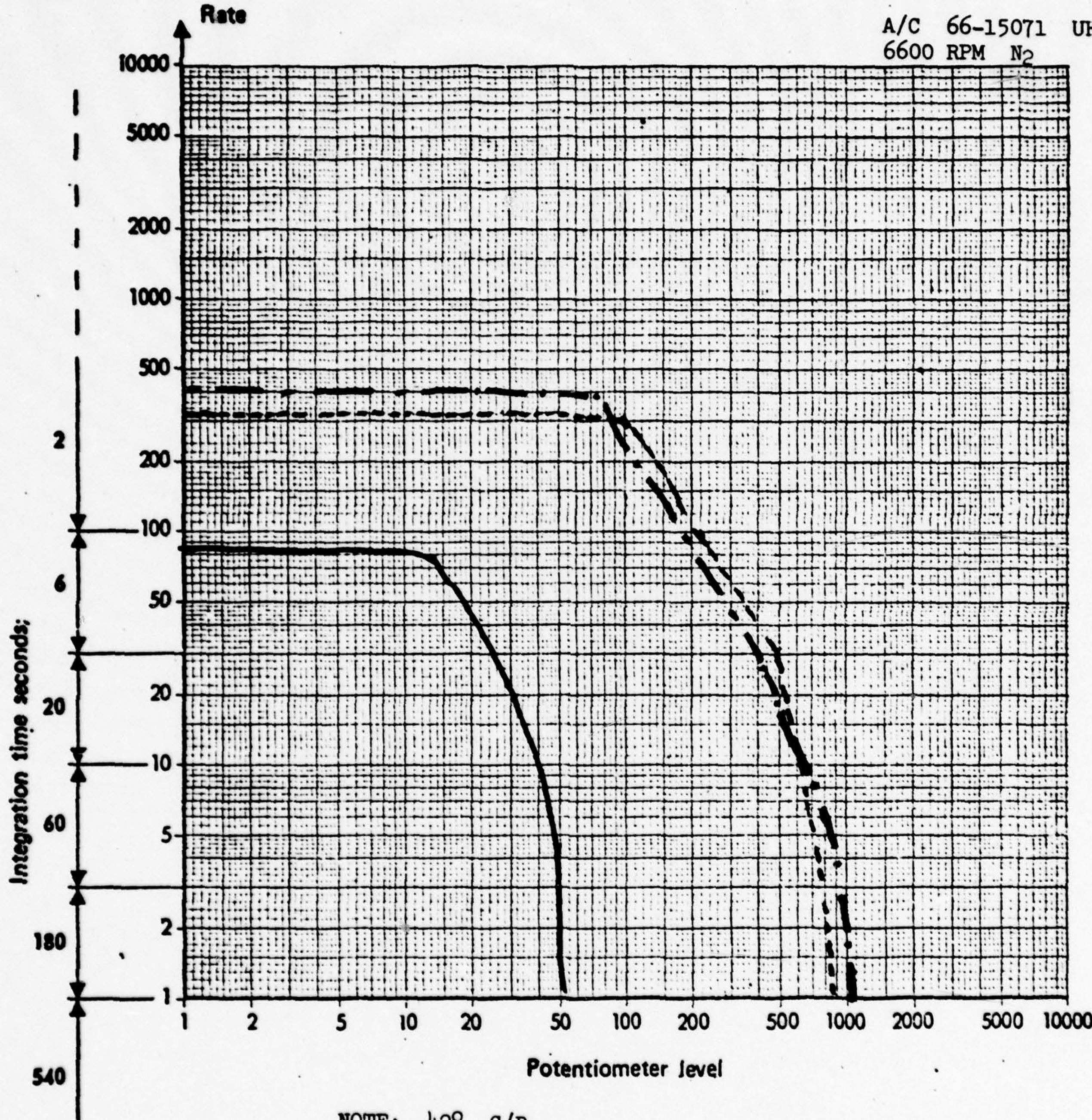


NOTE: #2 Hanger Bearing ------------------
#3 Hanger Bearing ________________
Mast ____ _ ____ _ ____ . ___

281st Aviation Company Bi State Airport 6 Aug 74

42° Gear Box Input . BBB-1894
#3 Hanger Bearing A20-31517
~~Input Drive Quill~~

A/C 66-15071 UH-1C
6600 RPM N_2



NOTE: 42° G/B ______________

#3 Hanger Bearing -------

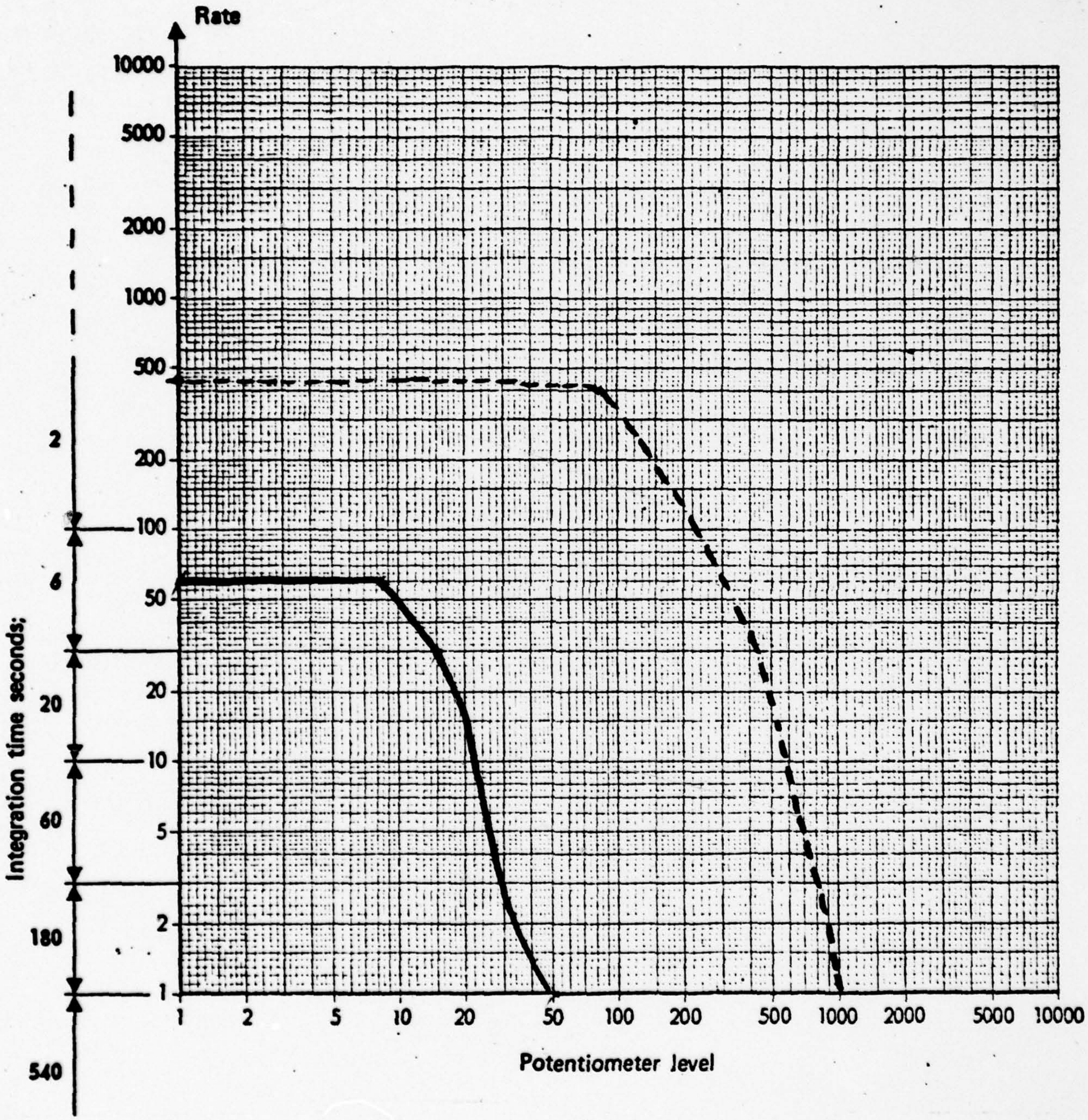
Input Drive Quill ____ _ ____ _ ____

281st Aviation Company Bi State Airport 6 Aug 74

#1 Hanger Bearing

Mast Bearing

A/C 66-15071 UH-1C
6600 RPM N_2



NOTE: #1 Hanger Bearing ________________

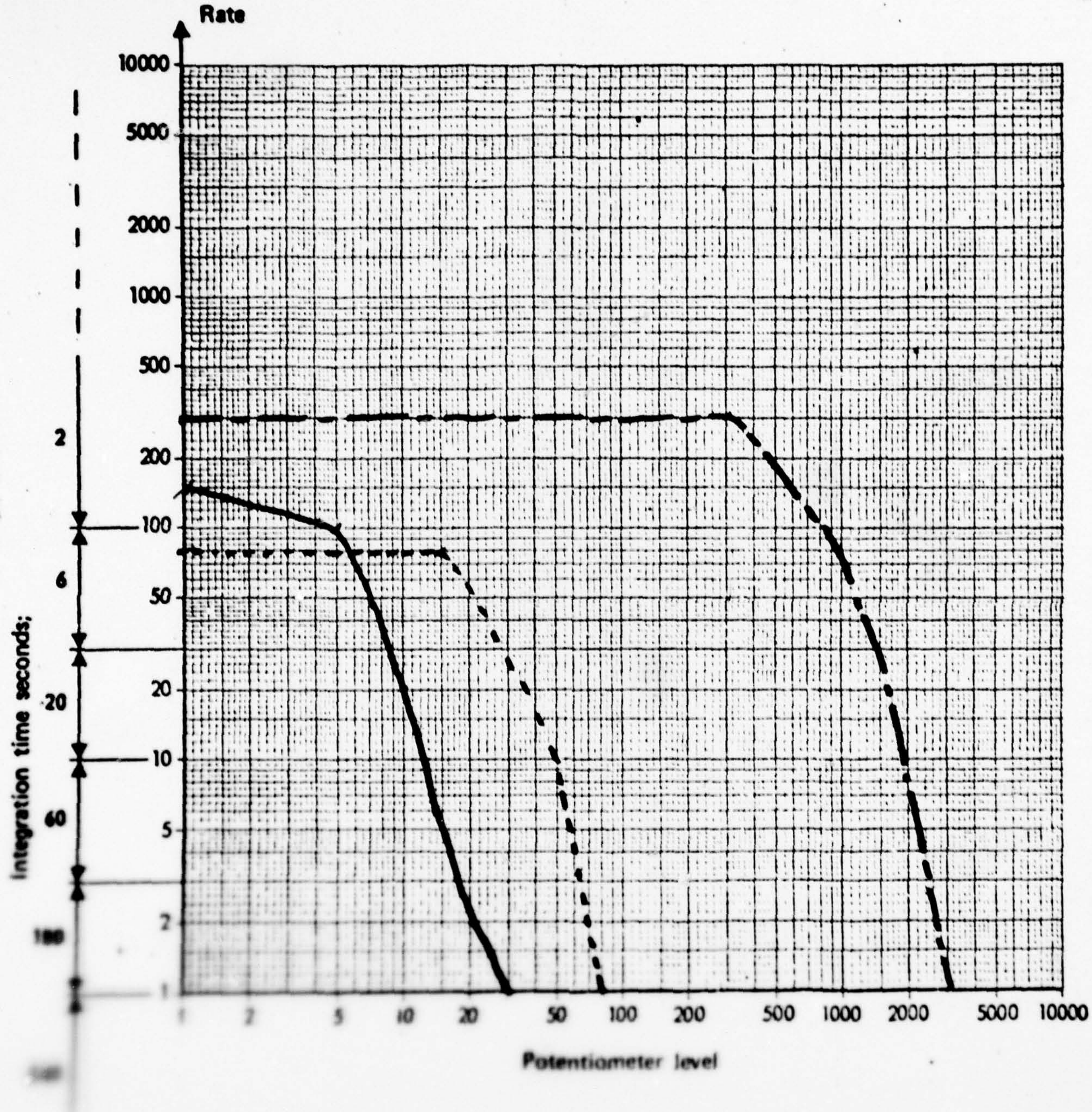
Mast Bearing ------------

74

281st Aviation Company Bi State Airport 6 Aug 74

90° Gear Box B13-3307
42° Gear Box Output BBB-1894
#2 Hanger Bearing A20-15990

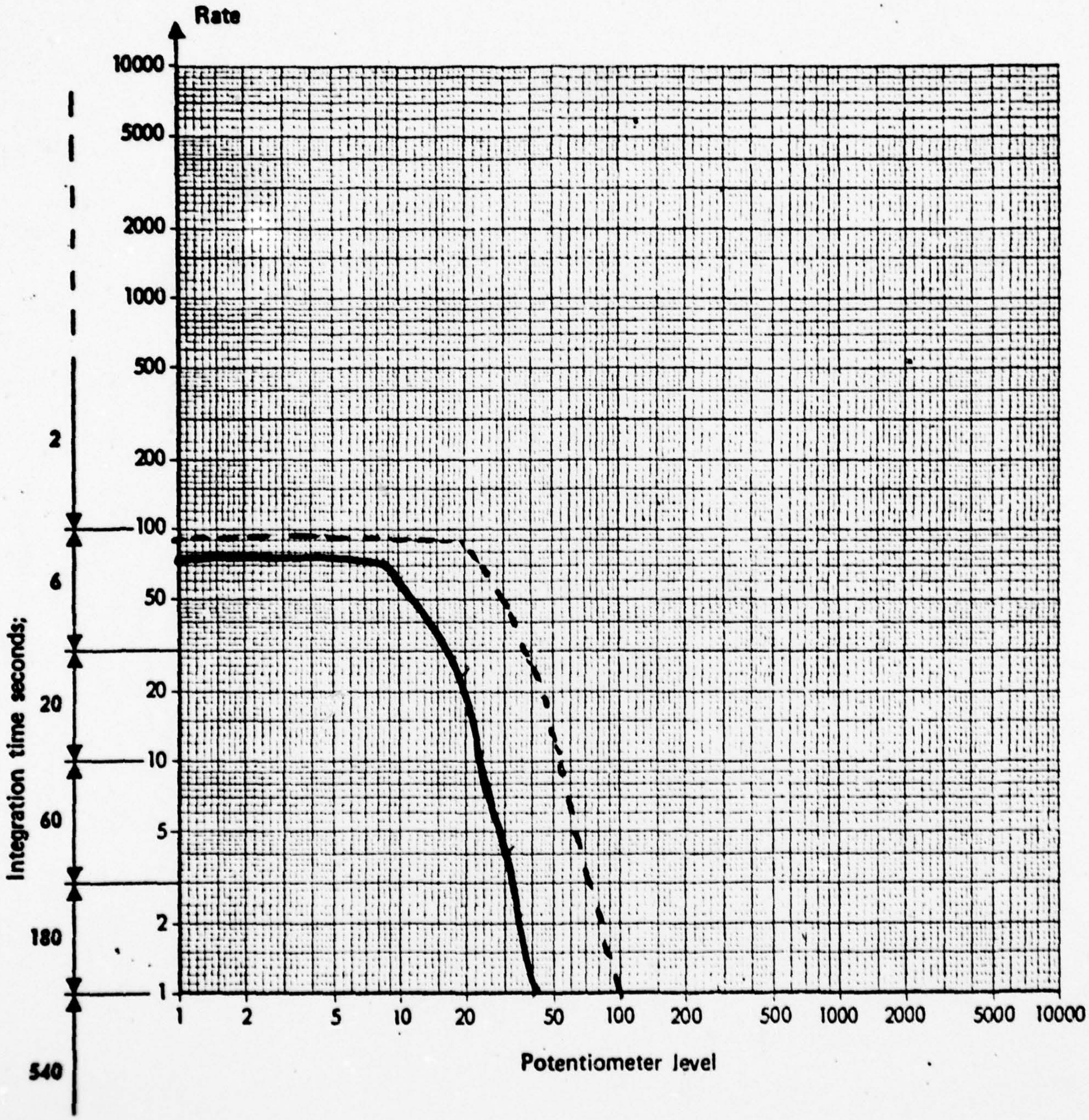
A/C 66-15071 UH-1C
6600 RPM N_2



281st Aviation Company - Bi State Airport 7 Aug 74

Mast Bearing
Input Drive

A/C 65-9771 UH-1H
6600 RPM N_2



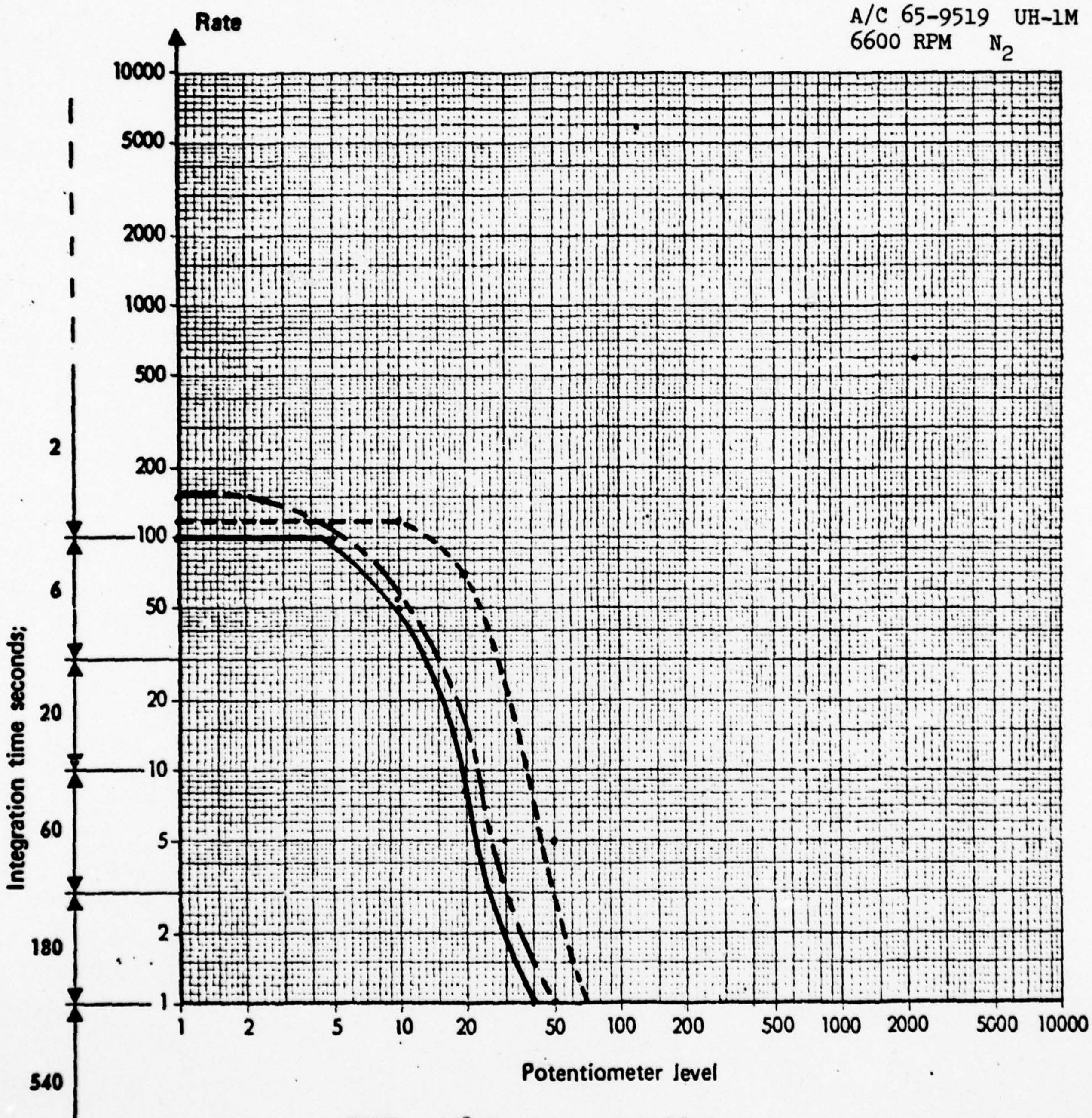
NOTE: Mast Bearing ____________

Input Drive- - - - - - - - - - - -

281st Aviation Company Bi State Airport 8 Aug 74

90° Gear Box
#3 Hanger Bearing
#2 Hanger Bearing

A/C 65-9519 UH-1M
6600 RPM N_2



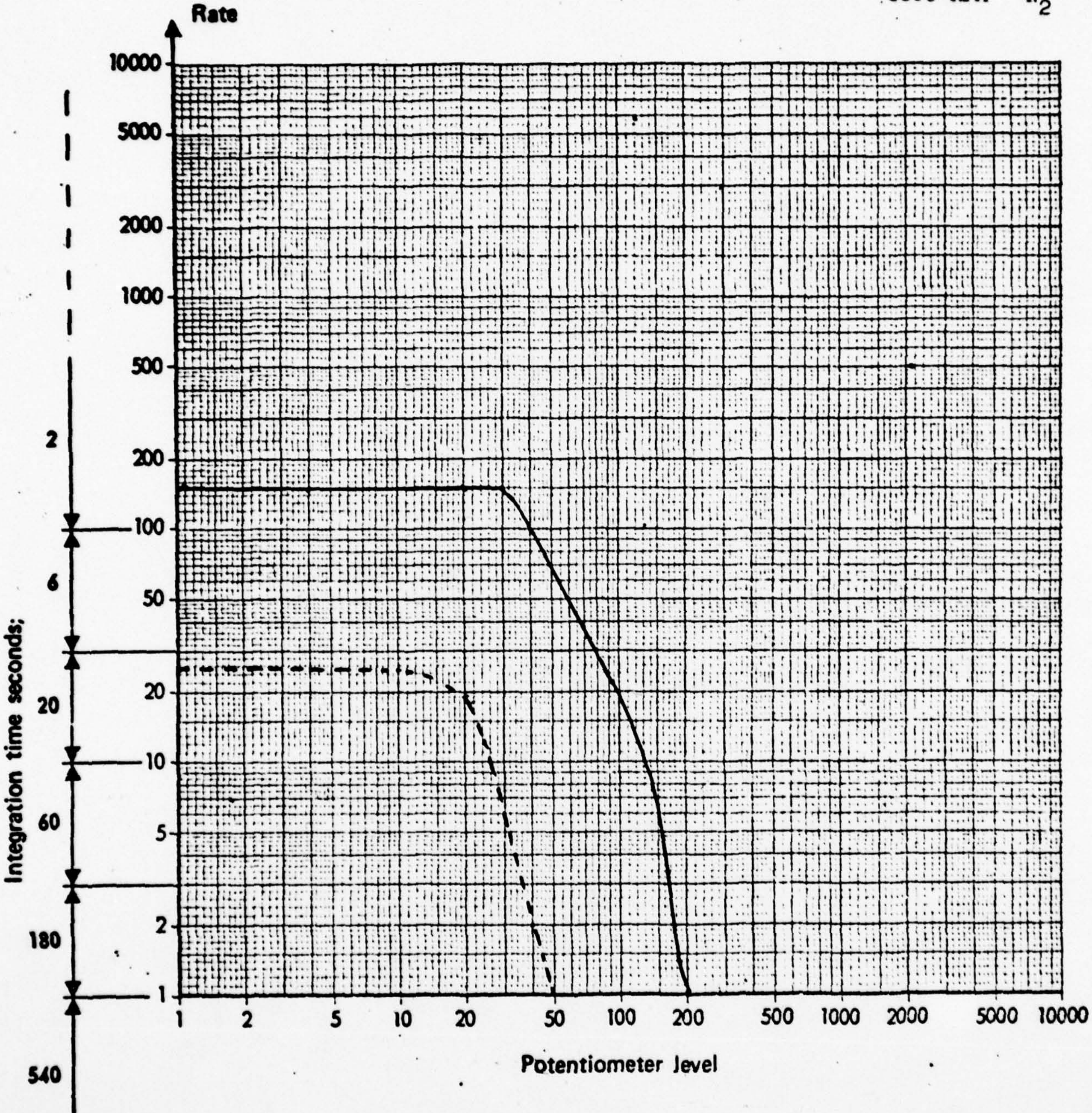
NOTE: 90° Gear Box B13-8655
#3 Hanger Bearing A20-26938
#2 Hanger Bearing A20-57910

281st Aviation Company Bi State Airport 8 Aug 74

Input Drive Quill

Mast Bearing

A/C UH-1M 65-9519
6600 RPM N_2



NOTE: Input Drive Quill ______________

Mast Bearing -------------

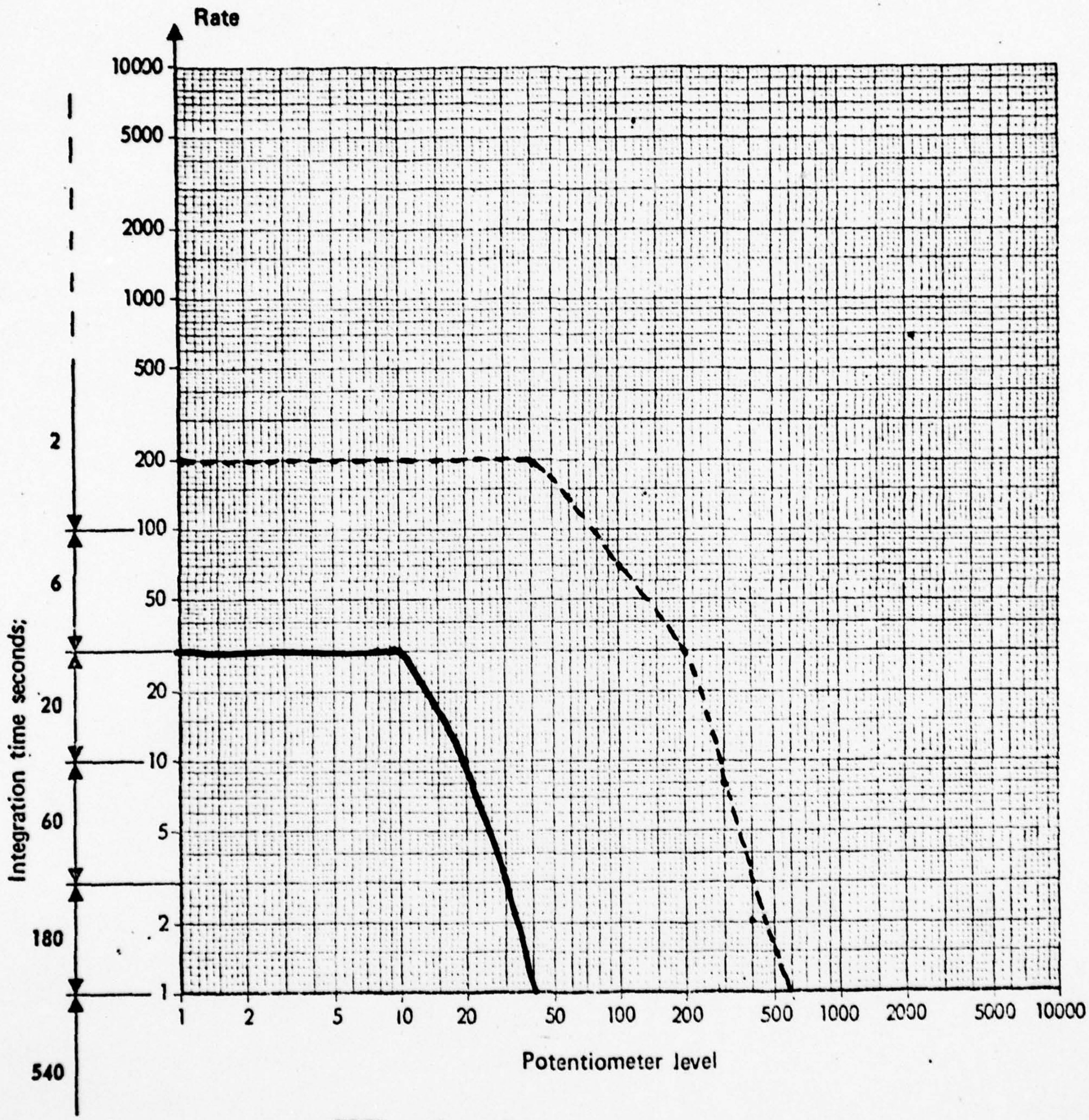
281st Aviation Company Bi State Airport 9 Aug 74

42° Gear Box Input

#1 Hanger Bearing

A/C UH-1M 66-15091

6600 RPM N_2



NOTE: Aircraft tested while raining

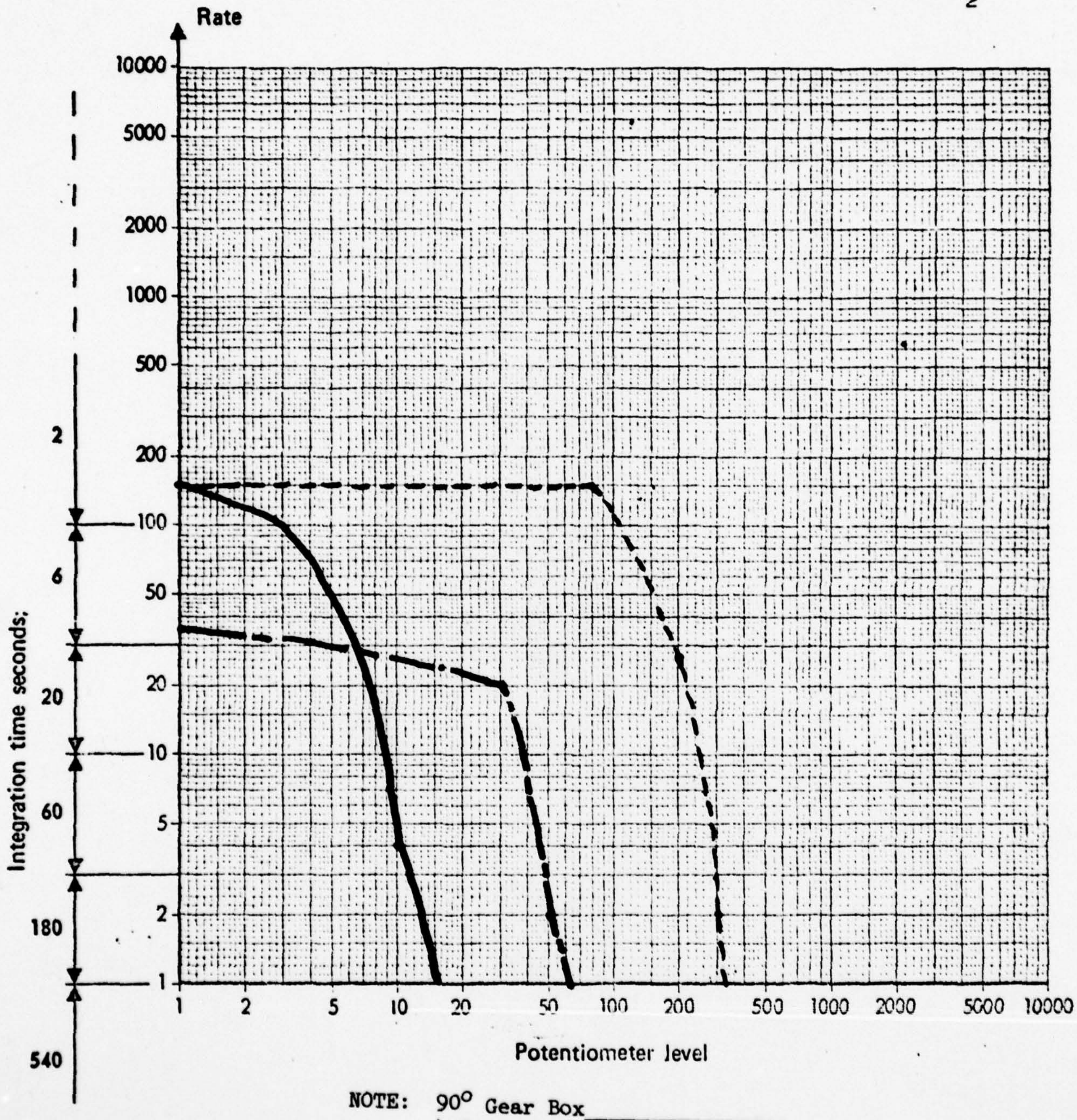
42° G/B input____________

#1 Hanger Bearing------------

281st Aviation Company Bi State Airport 12 Aug 74

90° Gear Box
42° Gear Box Output
42° Gear Box Input

A/C UH-1H 70-16354
6600 RPM N_2

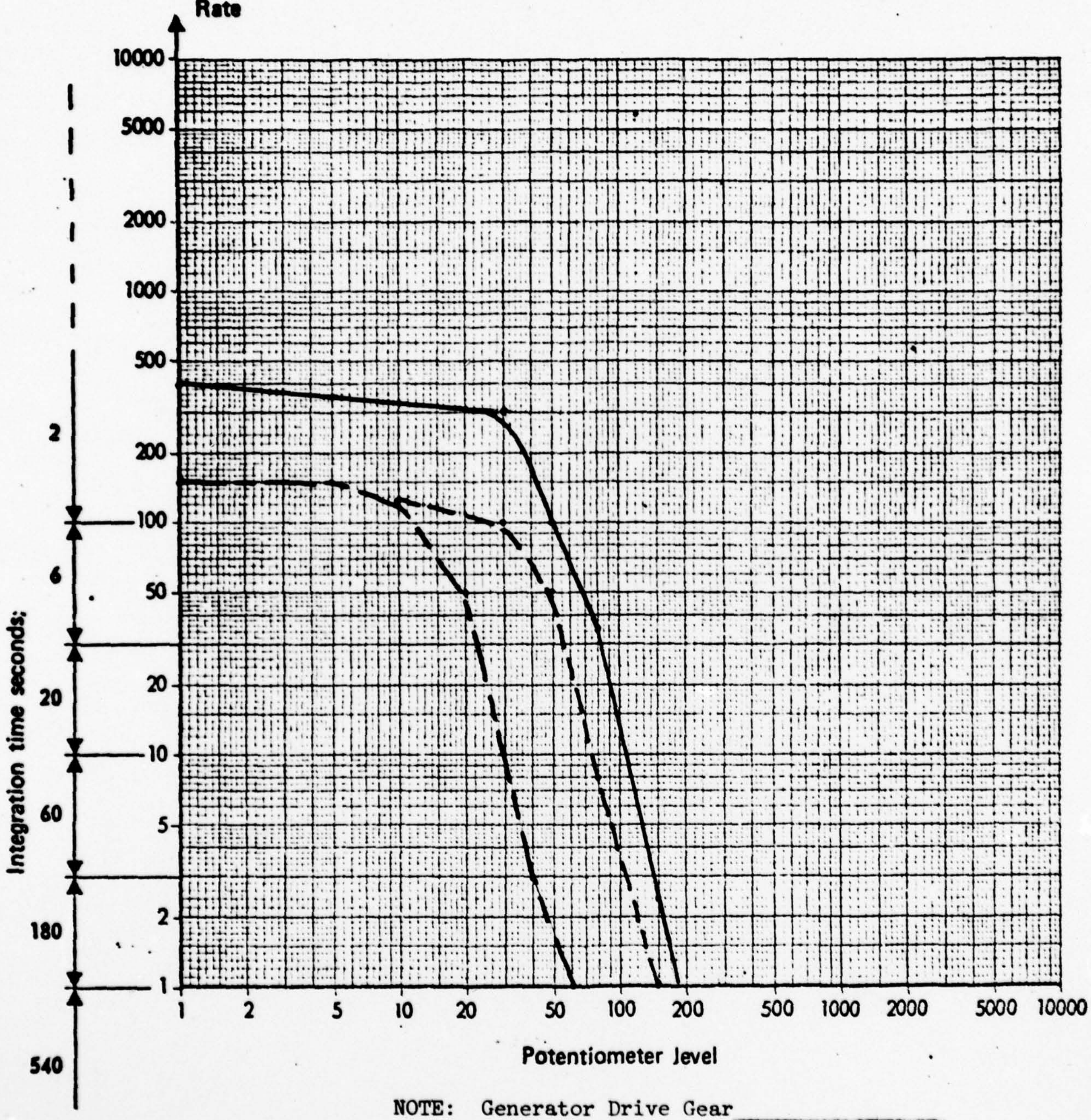


NOTE: 90° Gear Box ______________
42° Gear Box Output---------
42° Gear Box Input _____ _ _____ _ _____

281st Aviation Company Bi State Airport 12 Aug 74

Generator Drive Gear
Input Drive
Mast Bearing

A/C UH-1H 70-16354



NOTE: Generator Drive Gear________________
Input Drive------------------
Mast Bearing______ _ ______ _ _______

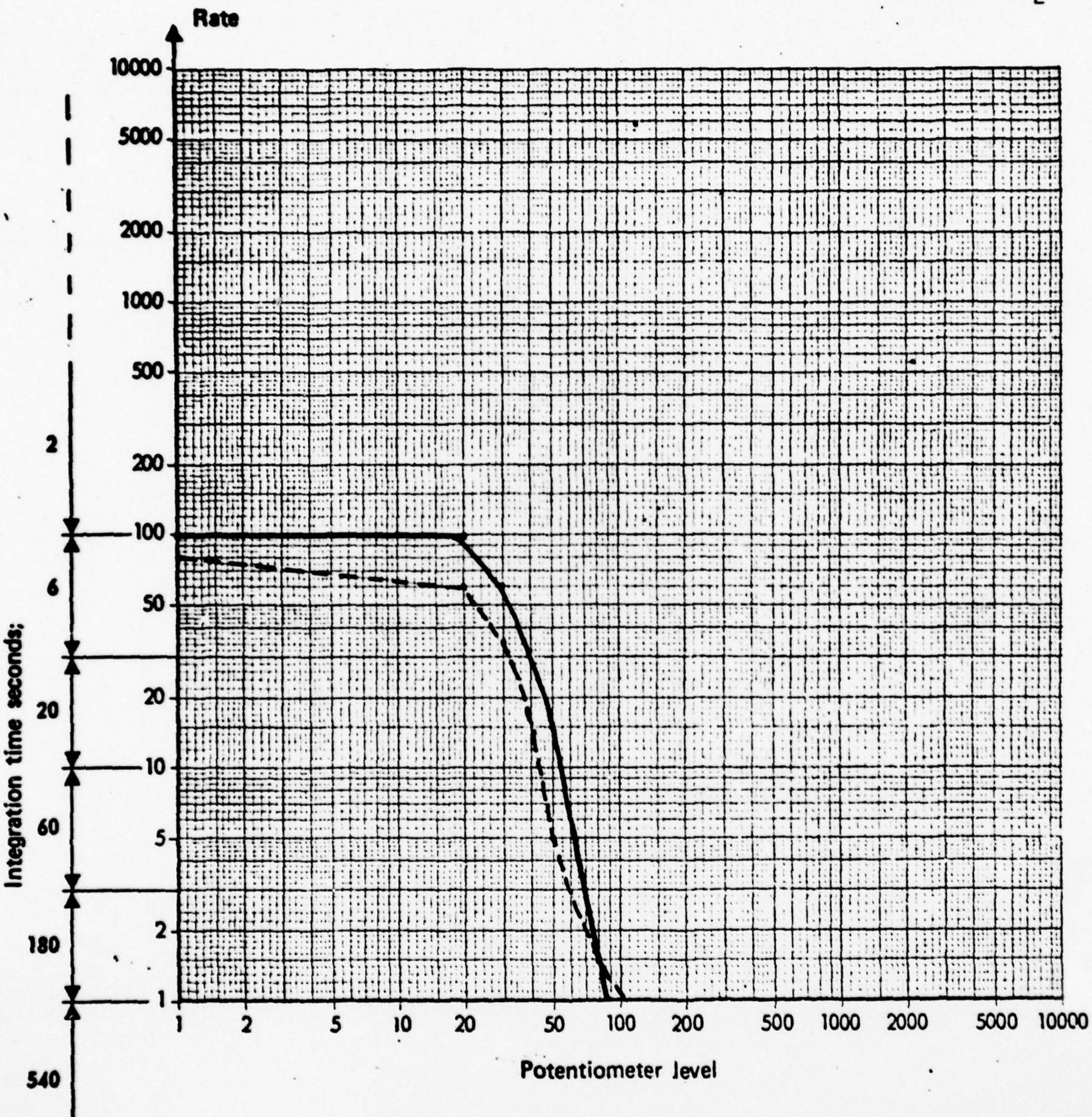
281st Aviation Company Bi State Airport 14 Aug 74

42° Gear Box Output

Mast Bearing

A/C UH-1D 66-16779

6600 RPM N_2



NOTE: 42° Gear Box Output__________________

Mast Bearing------------------

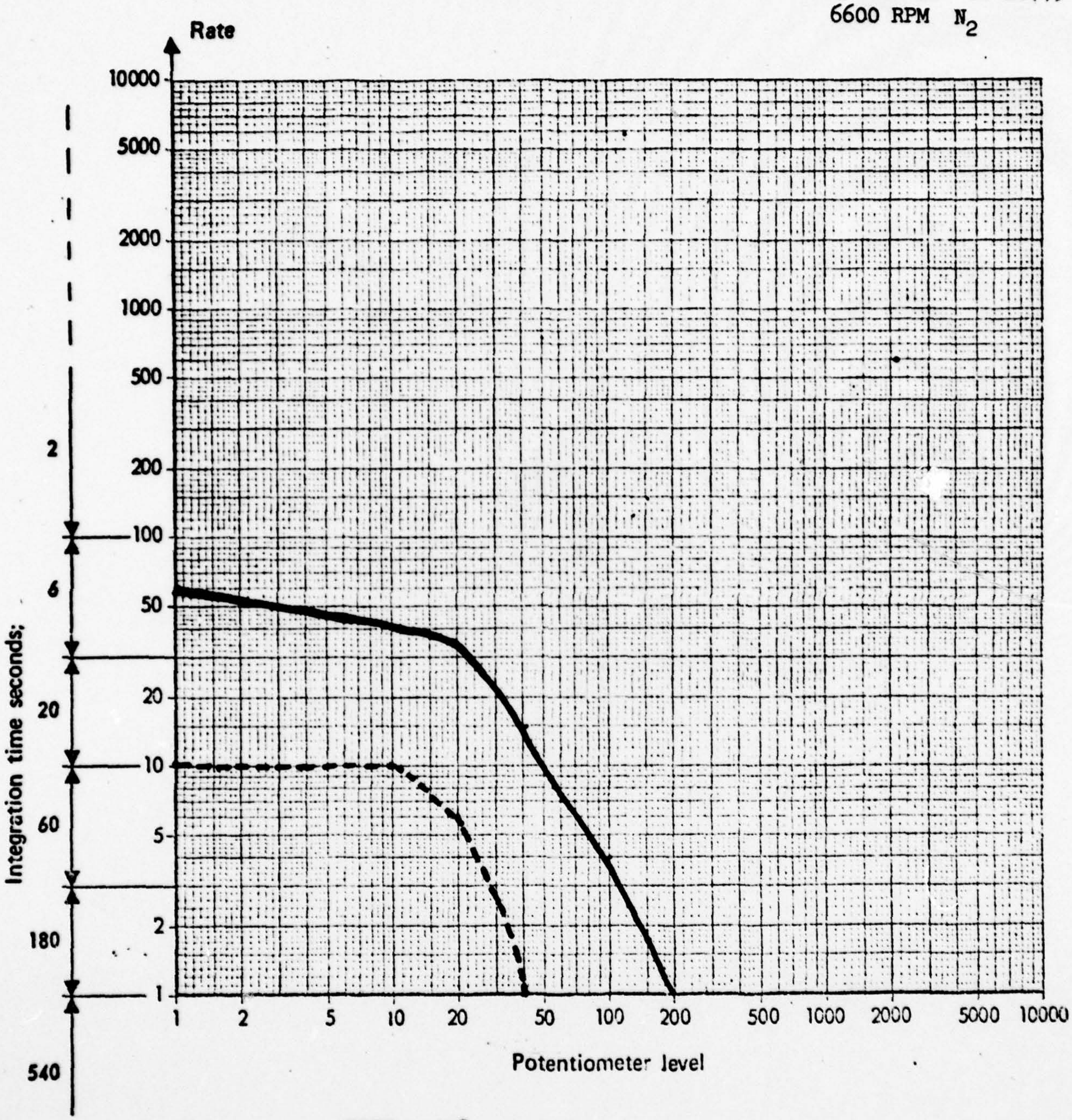
281st Aviation Company Bi State Airport 14 Aug 74

90° Gear Box

42° Gear Box Input

A/C UH-1D 66-16779

6600 RPM N_2



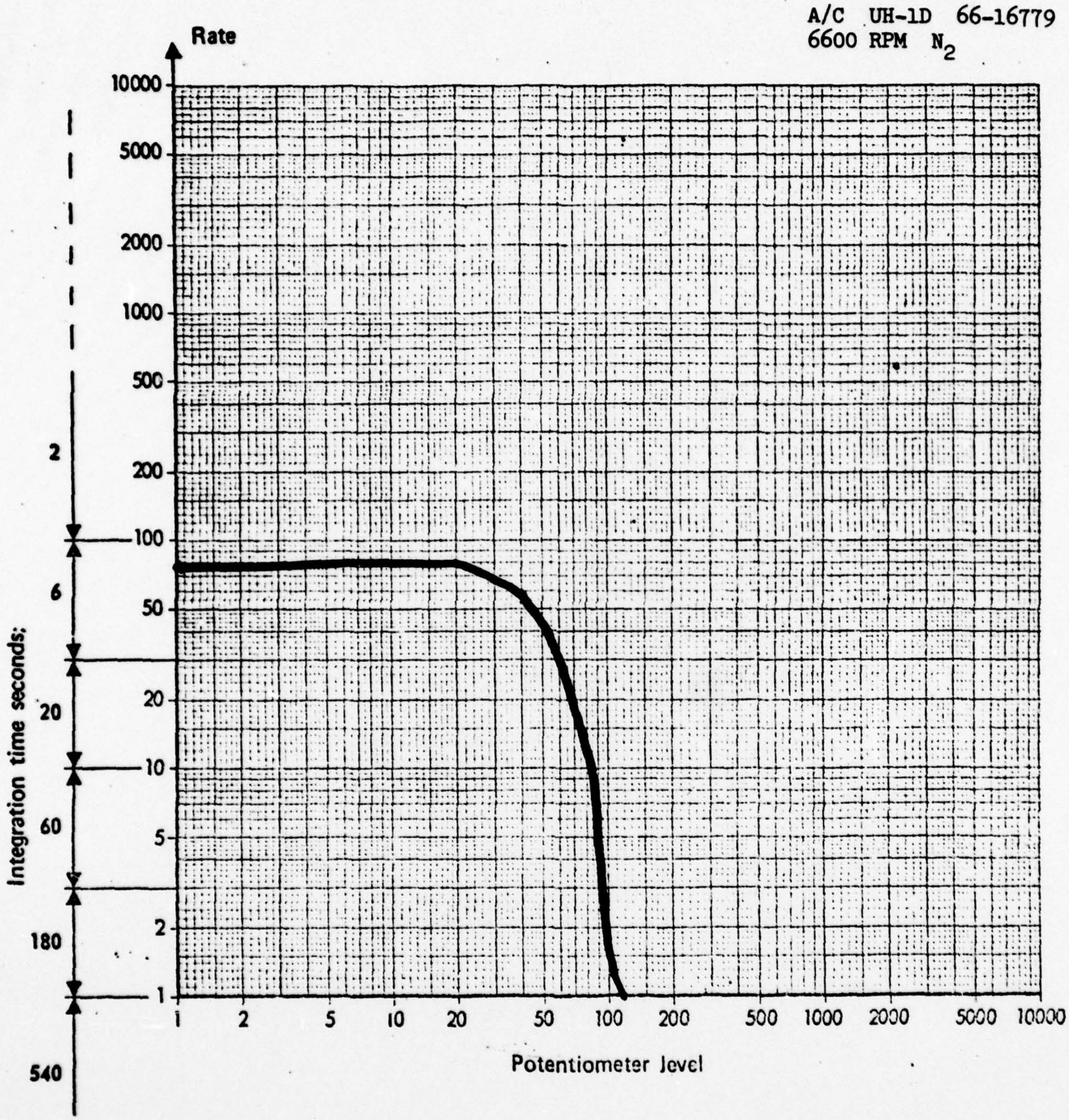
NOTE: 90° Gear Box____________________

42° Gear Box--------------------

281st Aviation Company Bi State Airport 14 Aug 74

Input Drive Quill

A/C UH-1D 66-16779
6600 RPM N_2



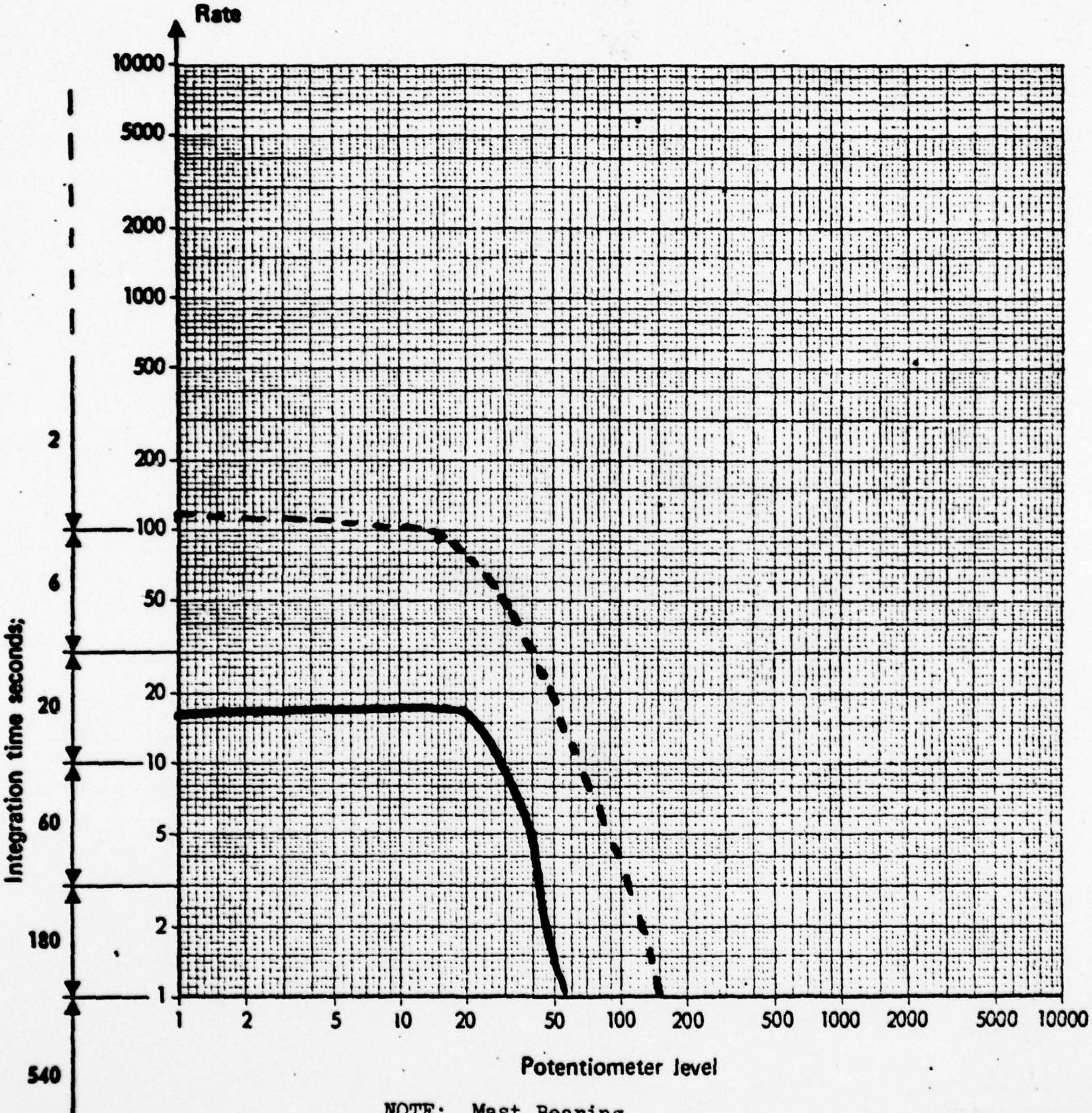
281st Aviation Company Bi State Airport 16 Aug 74

Mast Bearing

Input Drive Quill

A/C 66-01087 UH-1H

6600 RPM N_2



NOTE: Mast Bearing

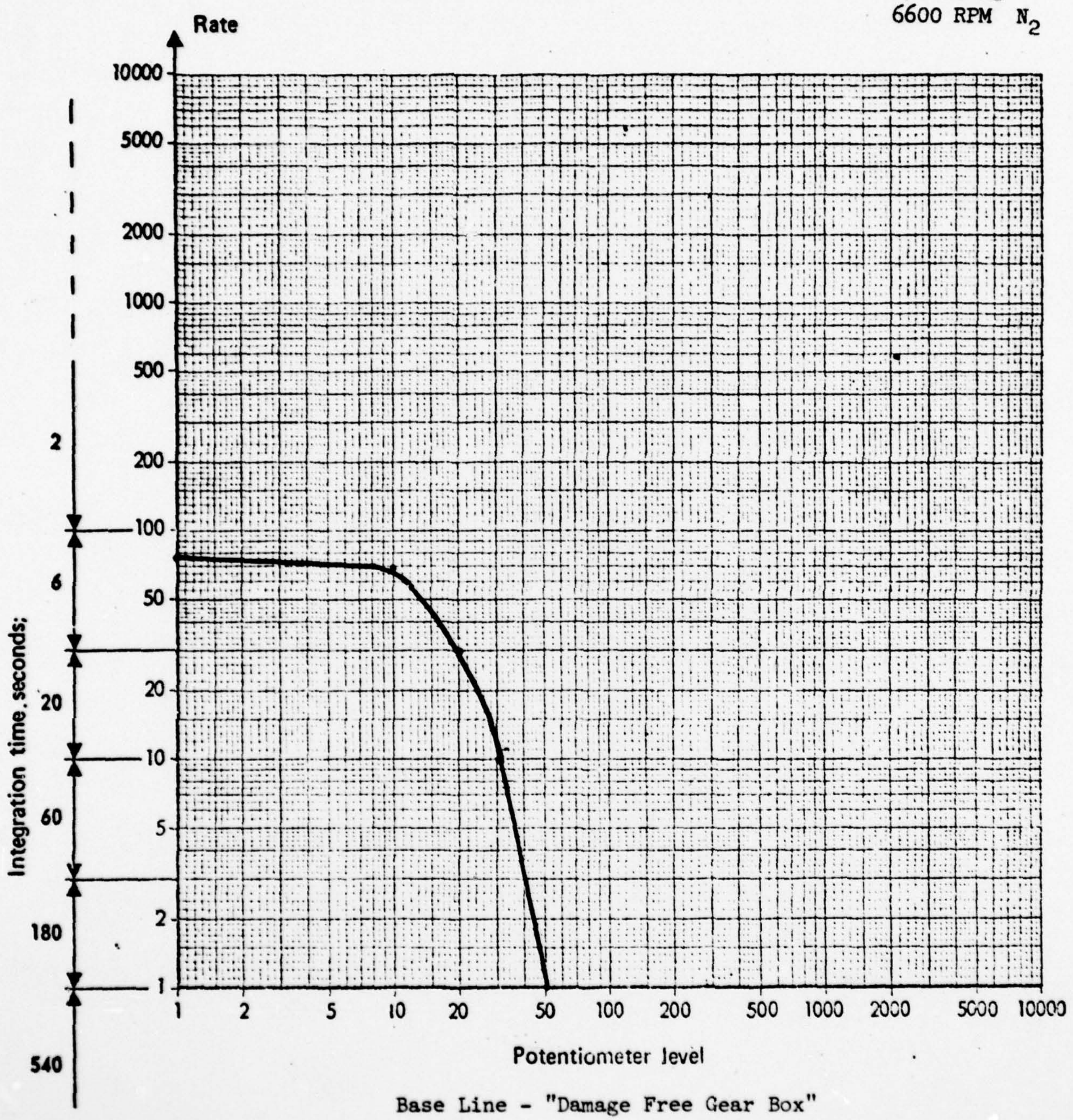
Input Drive Quill------------

APPENDIX 2.2

Ft. Rucker, Al. 13 June 74

4$2^{o}$ Gear Box

#B13-4312 (F-B)
A/C BC 13
6600 RPM N_2

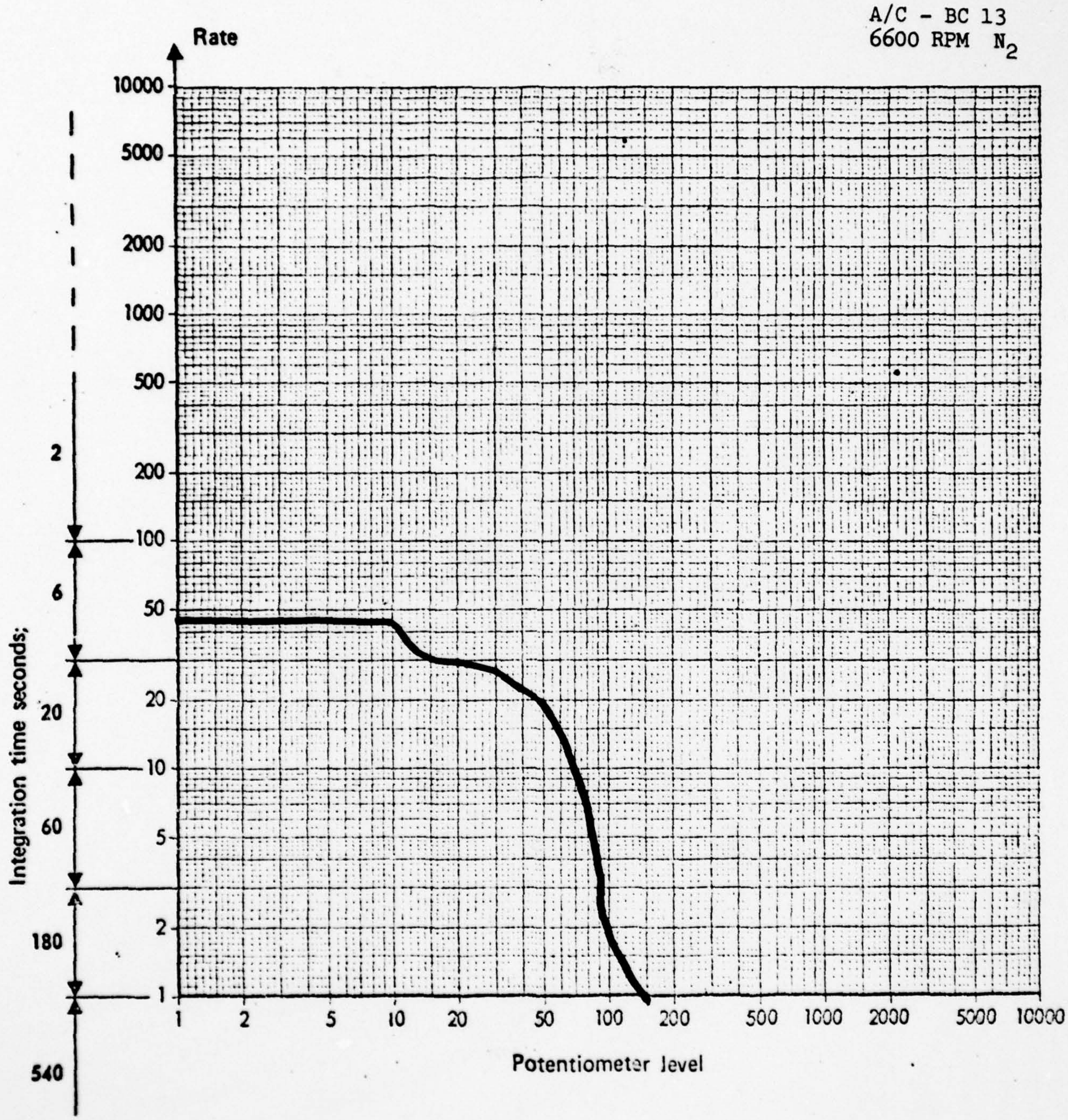


Base Line - "Damage Free Gear Box"

Ft. Rucker, Al. (U.S. Army Test Board) 13 Jun 74

#3 Hanger Bearing

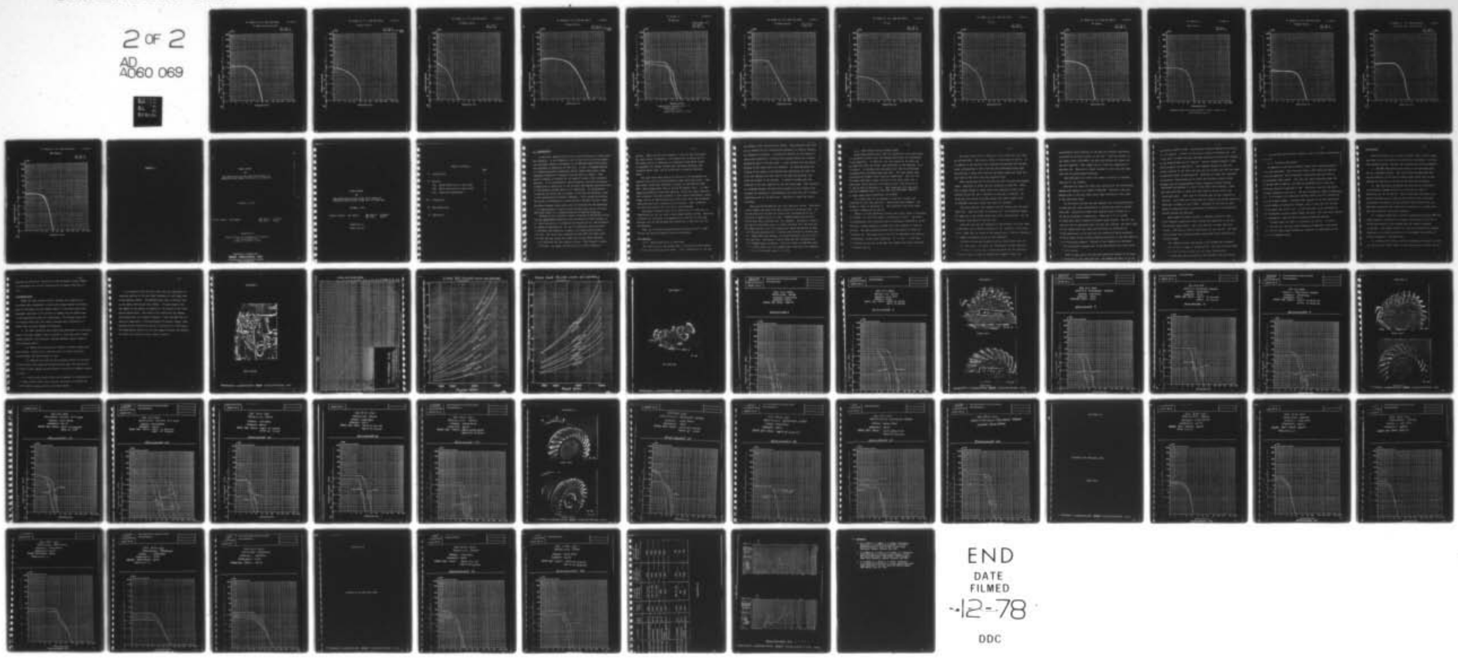
A/C - BC 13
6600 RPM N_2



AD-A060 069 PARKS COLL OF SAINT LOUIS UNIV CAHOKIA ILL F/G 13/9
SHOCK PULSE METER ANALYSIS.(U)
OCT 74 T C MAYER, E F COVILL, J A GEORGE DAAJ01-72-A-0027

UNCLASSIFIED USAAVRADCOM-TR-78-3 NL

2 OF 2
AD
A060 069

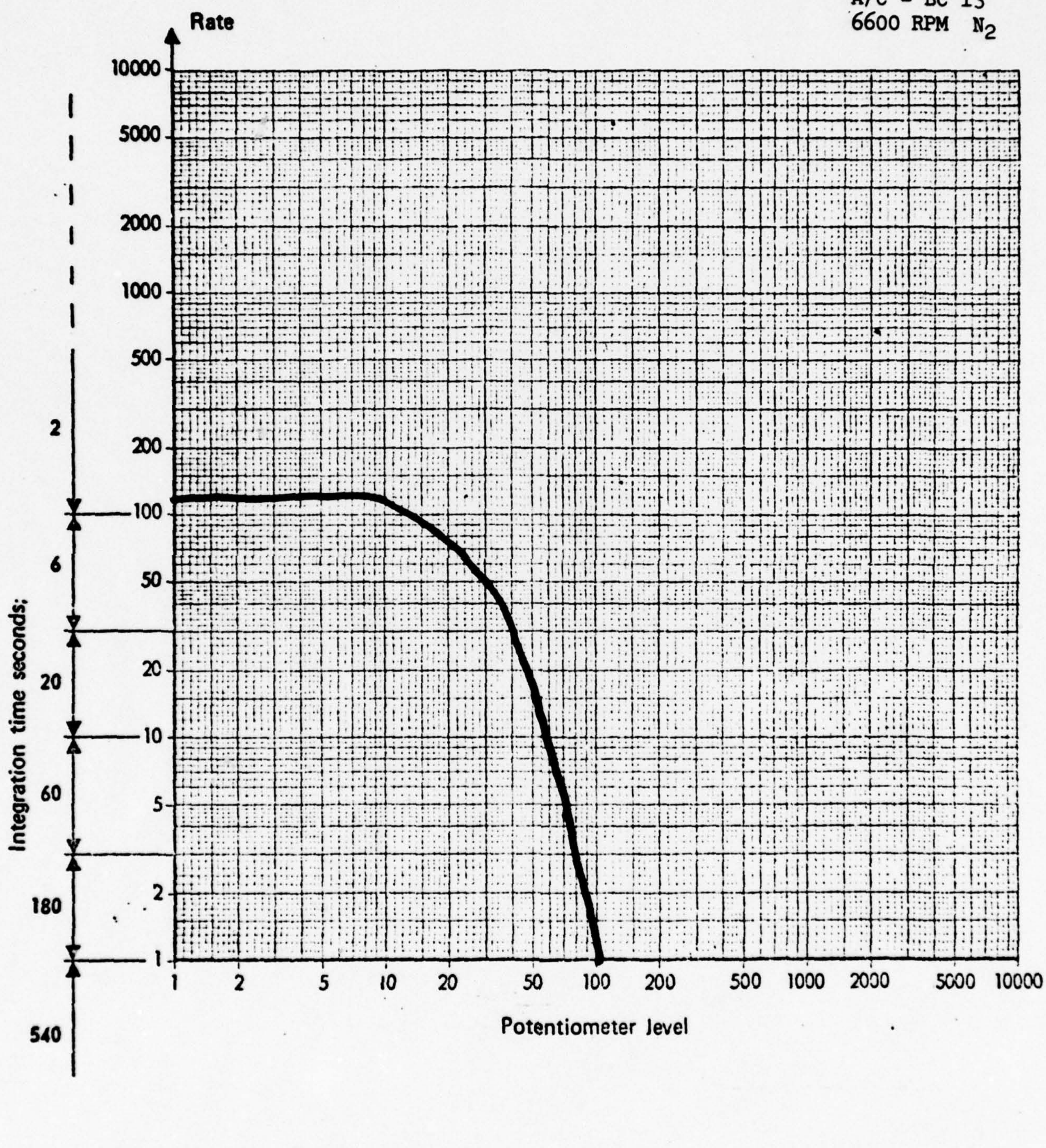


END
DATE
FILMED
12-78
DDC

Ft. Rucker Al. (U.S. Army. Test Board) 13 Jun 74

#4 Hanger Bearing A20-34779

A/C - BC 13
6600 RPM N_2

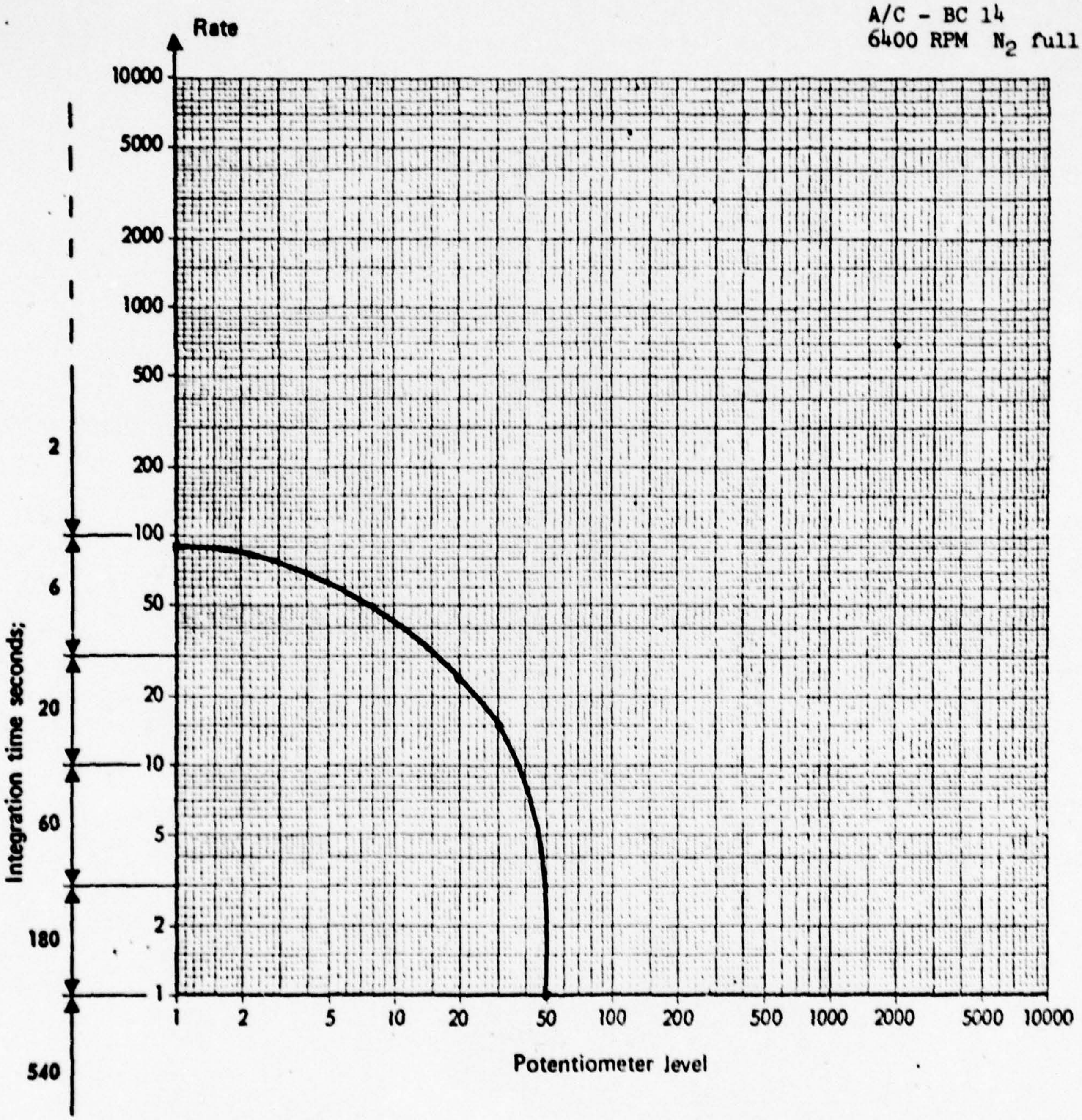


89

Ft. Rucker, Al. (U.S. Army Test Board) 13 Jun 74

#3 Hanger Bearing

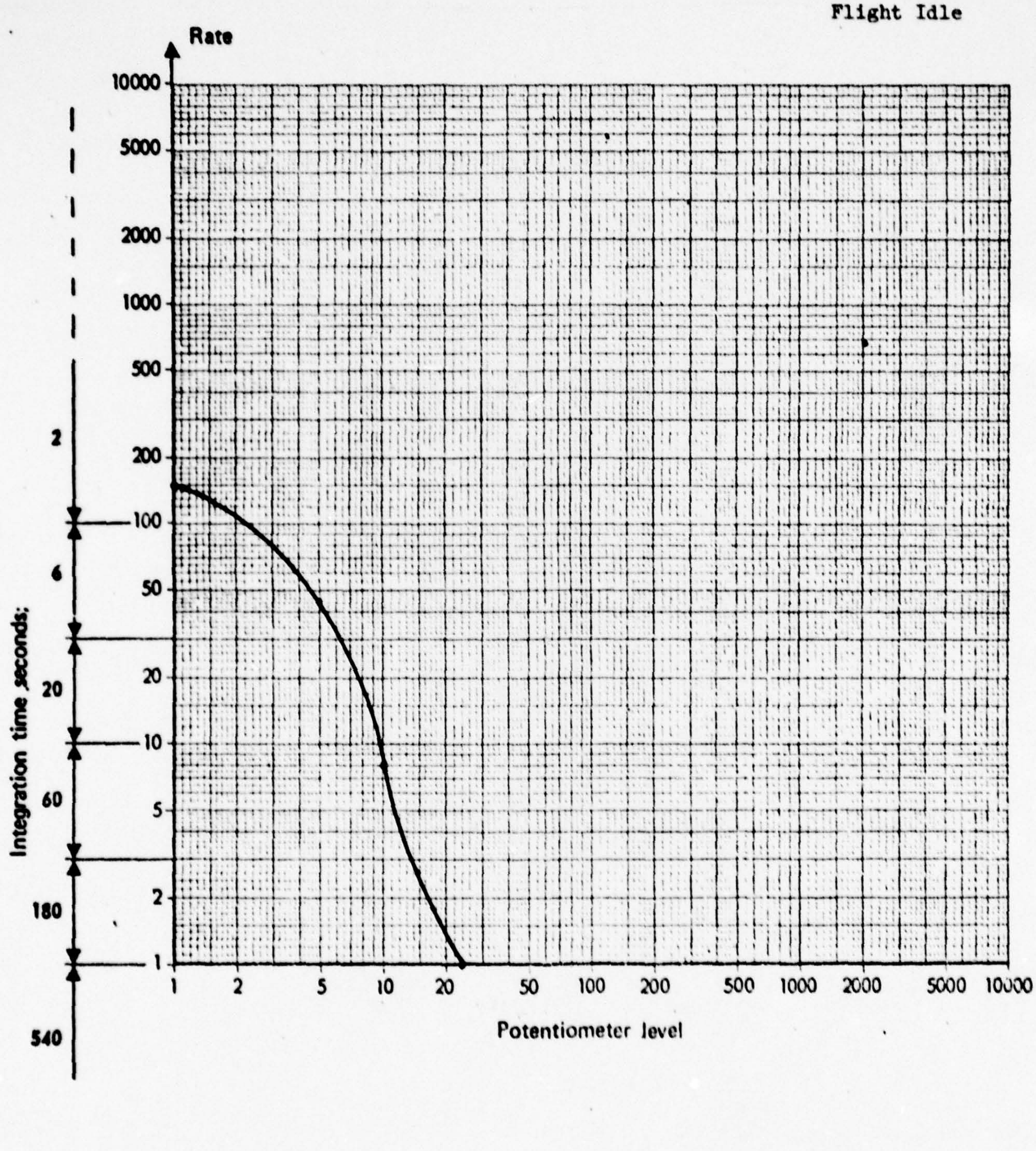
A/C - BC 14
6400 RPM N_2 full right pedal



Ft. Rucker, Al. (U.S. Army Test Board) 13 June 74

#3 Hanger Bearing

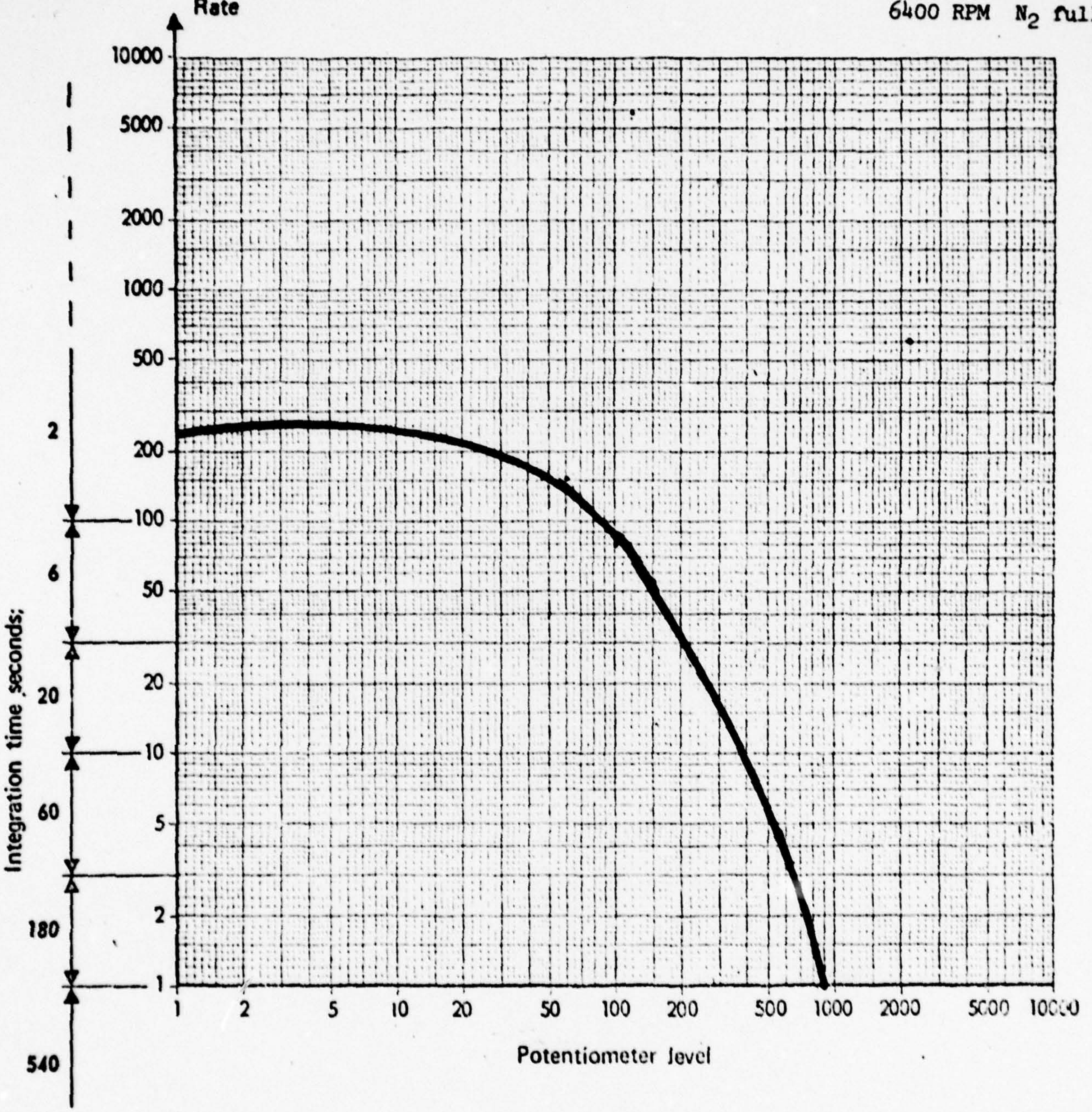
A/C - BC 14
Flight Idle



Ft. Rucker, Al. (U.S. Army Test Board) 13 Jun 74

#4 Hanger Bearing

A/C - BC 14
6400 RPM N_2 full left pedal

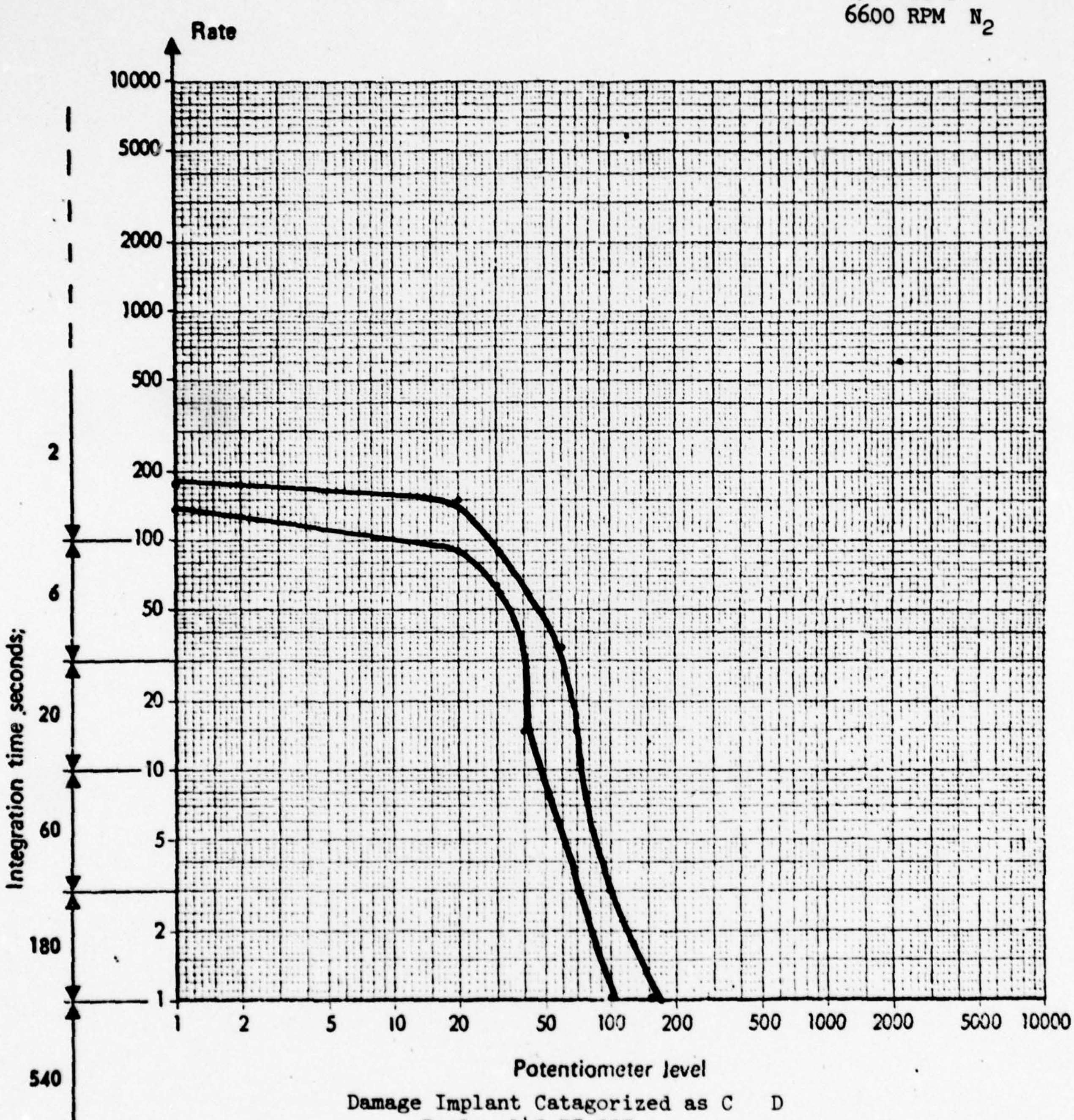


92

Ft. Rucker, Al. 13 June 74

42^{o} Gear Box

S/N B13-9881 (F-6)
A/C BC-14
6600 RPM N_2



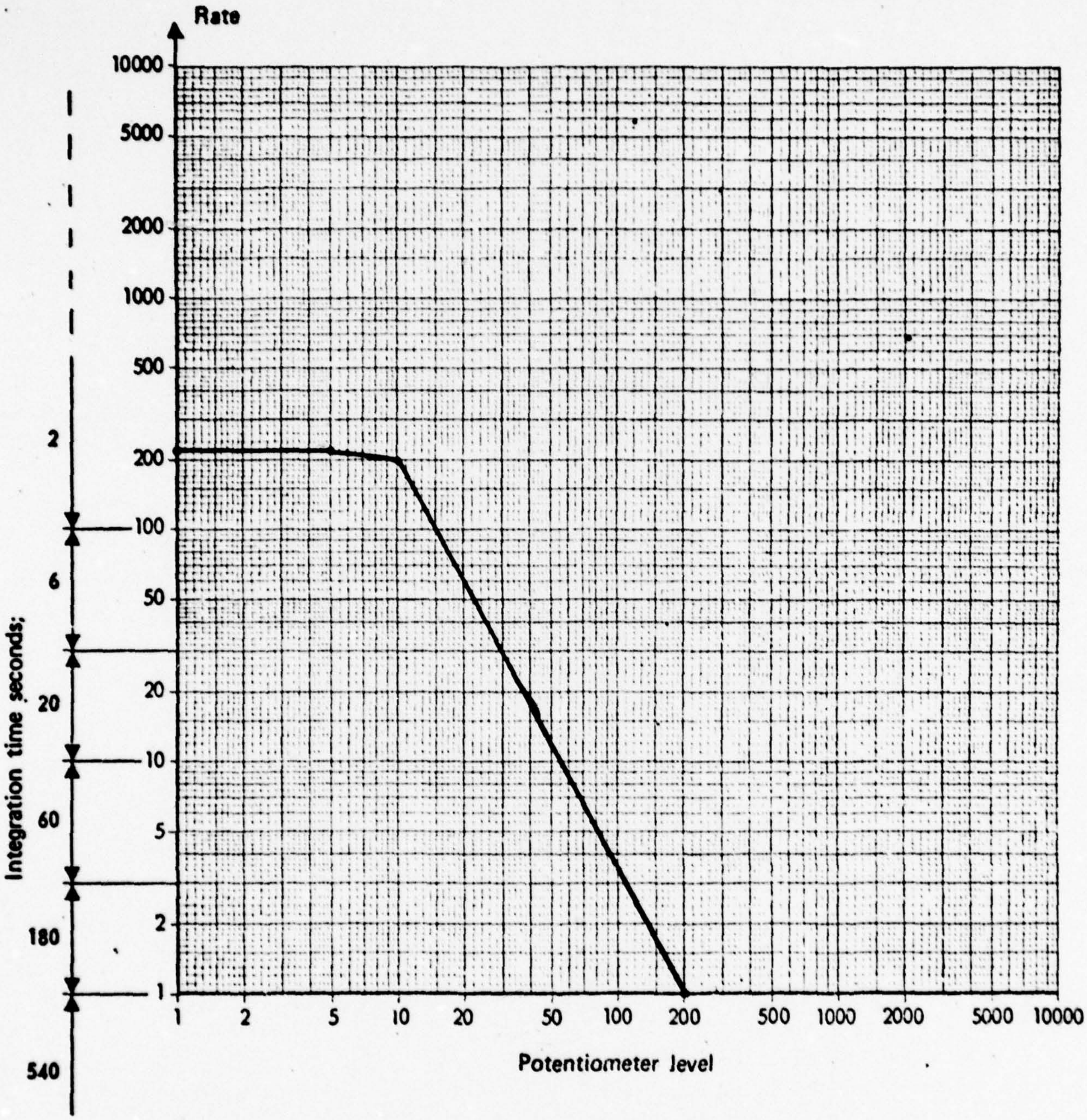
Damage Implant Catagorized as C D
Duplex 143 BI 007
S/N 41100 - 1 & 2
Average Data Scatter of 3 runs

93

Ft. Rucker, Al. (U.S. Army Test Board) 13 Jun 74

#4 Hanger Bearing

A/C - BC 14
Flight Idle

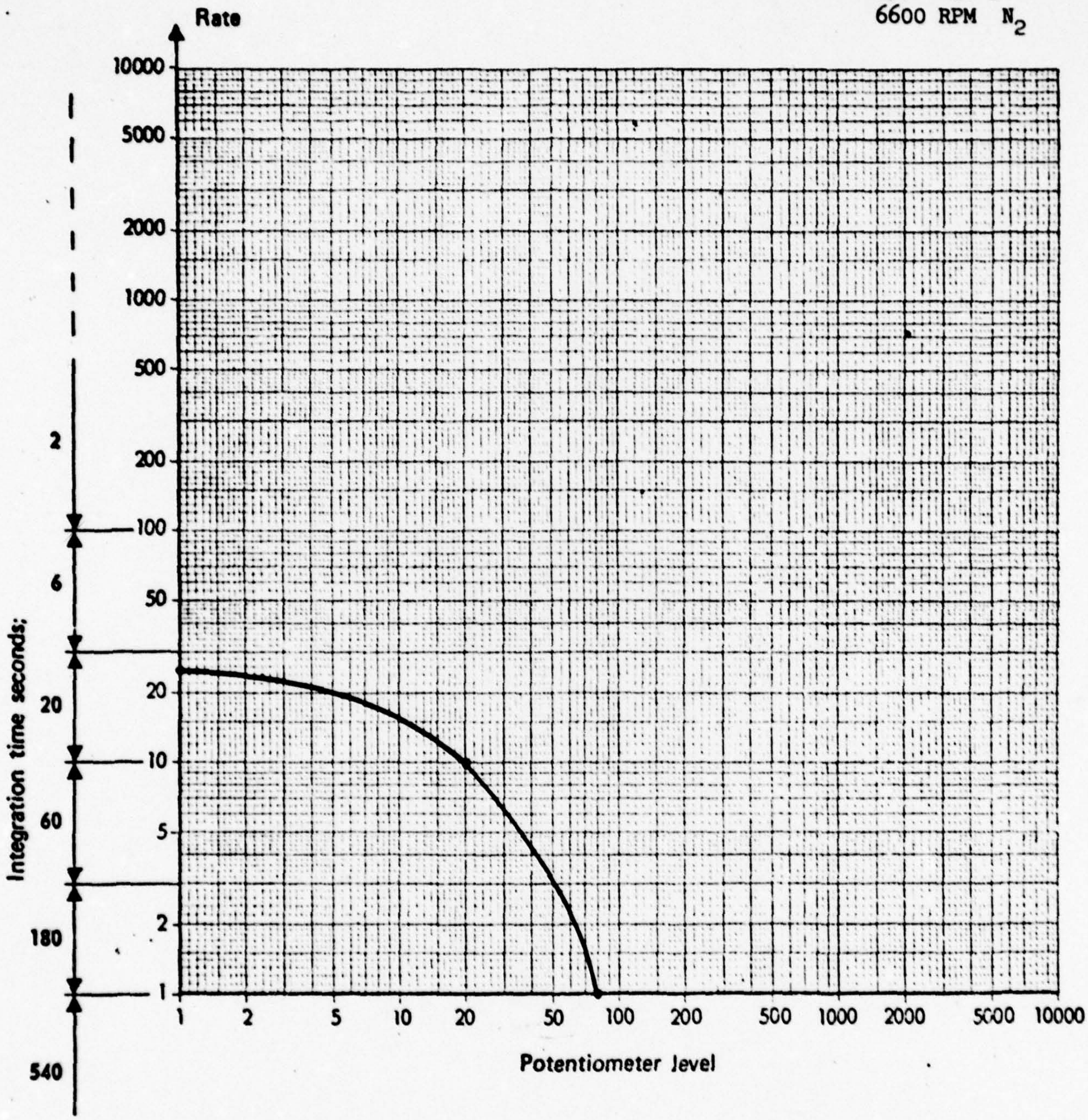


97

Ft. Rucker, Al. (U.S. Army Test Board) 13 Jun 74

42° g/b

A/C - BC 14
6600 RPM N_2

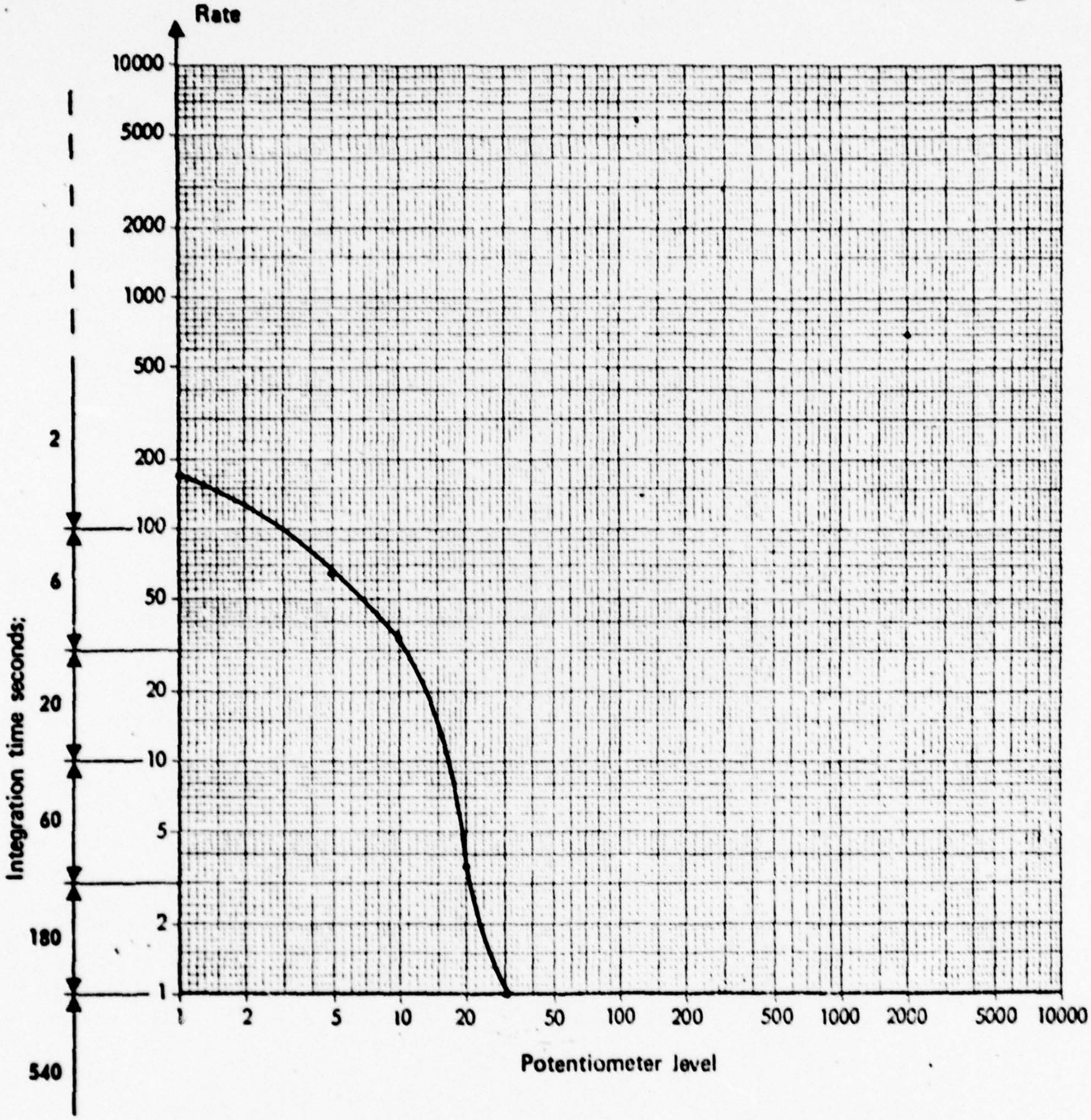


75

Ft. Rucker, Al. (U.S. Army Test Board) 13 Jun 74

42° g/b

A/C - BC14
6600 RPM N_2

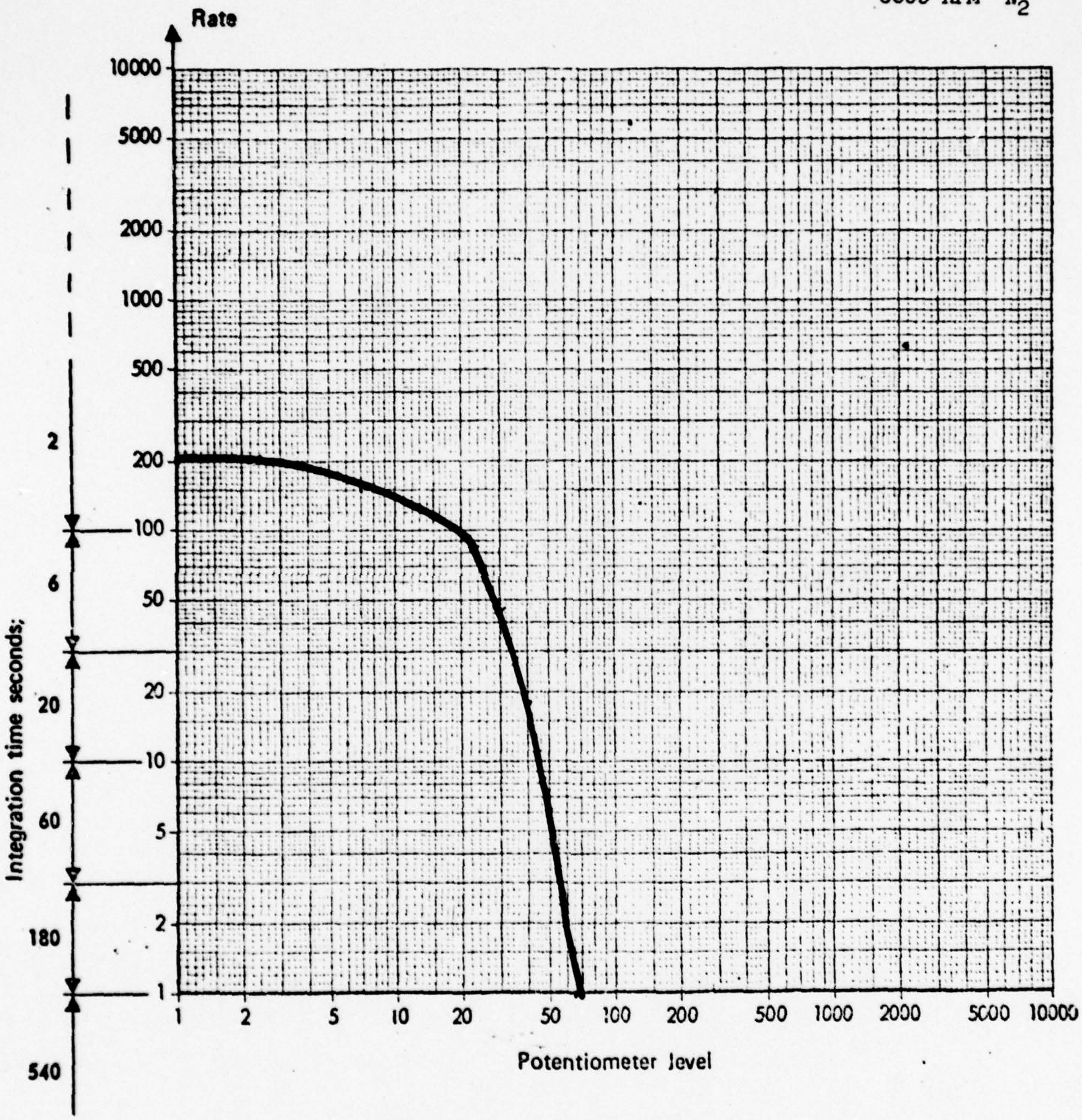


96

Ft. Rucker, Al. (U.S. Army Test Board) 13 Jun 74

42° Gearbox

A/C - BC 14
6600 RPM N_2

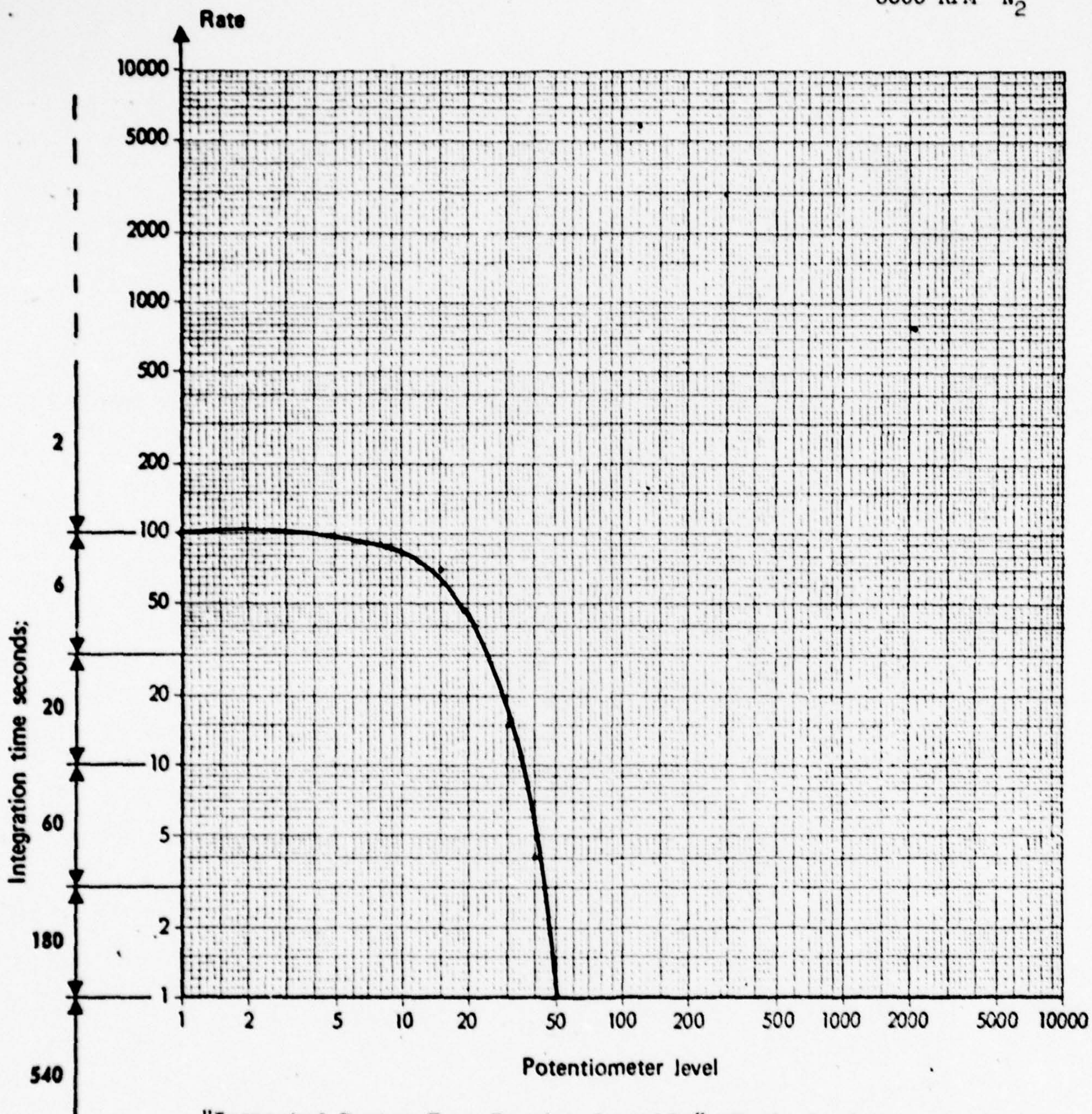


97

Ft. Rucker, Al. 14 June 74

Hanger Bearing

A/C BC 13
6600 RPM N_2



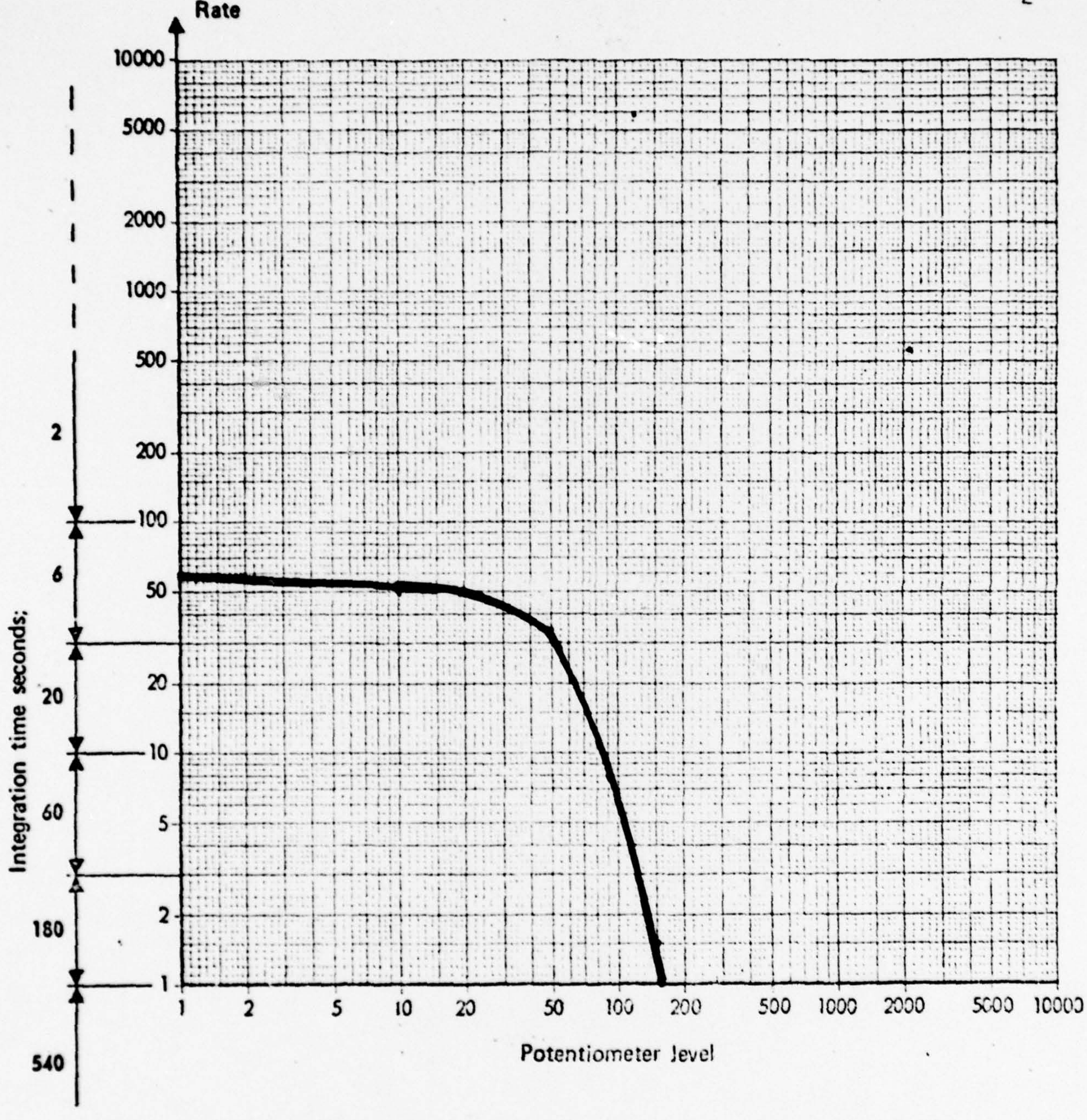
"Inspected Damage Free Bearing Assembly" Typical of new or low time assemblies tested.

98

Ft. Rucker, Al. (U.S. Army Test Board) 14 Jun 74

#3 Hanger Bearing

A/C - BC 13
6600 RPM N_2

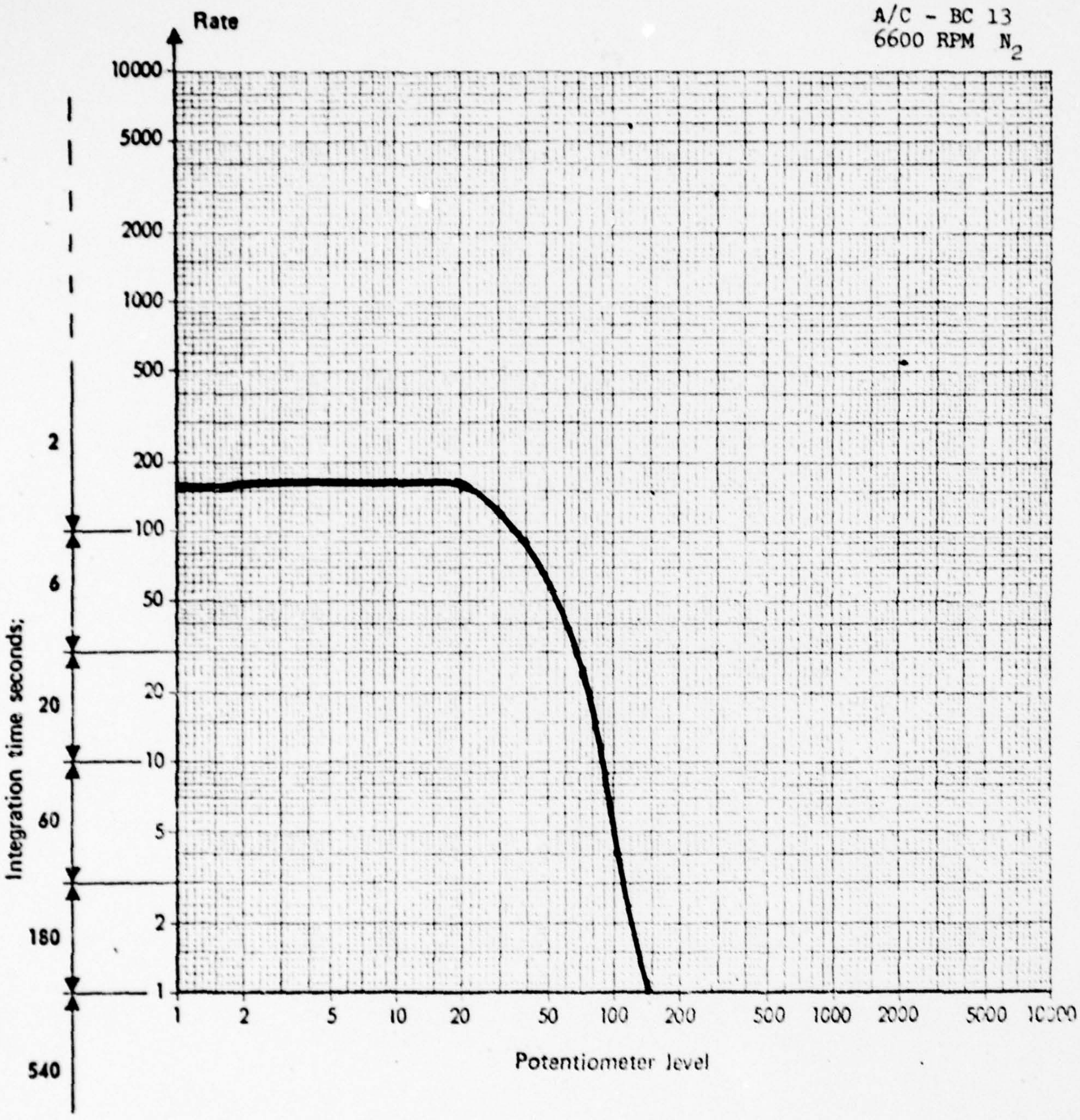


99

Ft. Rucker, Al. (U.S. Army Test Board) 14 Jun 74

Input Drive Quill ABU-11067 (M-6)

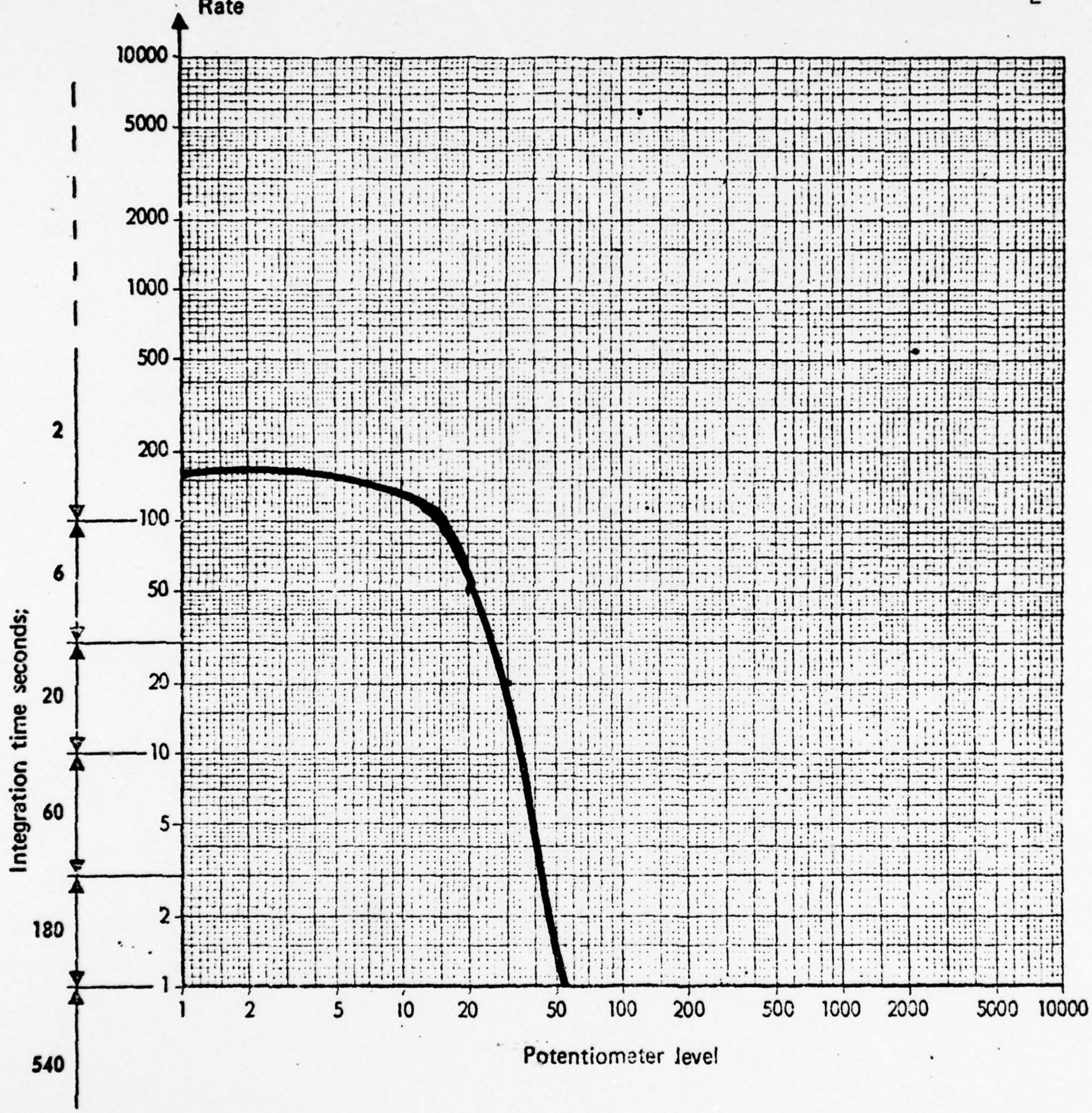
A/C - BC 13
6600 RPM N_2



Ft. Rucker, Al. (U.S. Army Test Board) 14 Jun 74

Mast Bearing

A/C - BC 13
6600 RPM N_2



101

APPENDIX 3.1

FINAL REPORT

ON

THE APPLICATION OF THE SHOCK PULSE METER IN DETECTING GEAR DAMAGE ON THE UH-1 42° GEAR BOX

October 8, 1974

Project Leader: Ned Hughes

SKF Report: AL74Q022
SKF Code: LC548

Submitted to:

Parks College of Aeronautical Technology
St. Louis University
Cahokia, Illinois 62206

RESEARCH LABORATORY
SKF INDUSTRIES, INC.
ENGINEERING AND RESEARCH CENTER
KING OF PRUSSIA, PA.

FINAL REPORT

ON

THE APPLICATION OF THE SHOCK PULSE METER IN DETECTING GEAR DAMAGE ON THE UH-1 42° GEAR BOX

OCTOBER 1974

Project Leader: Ned Hughes

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SKF Code: LC548

Submitted to:

Parks College

Table of Contents

		Page
I.	Introduction	1
II.	Details	2
	IIa. Shock Pulse Tests at Low Loads	2
	IIb. Shock Pulse Tests at High Loads	3
	IIc. Vibration Measurements	7
III.	Conclusions	9
IV.	Recommendations	9
V.	Enclosures	

I. INTRODUCTION

In the past, damage detection has consisted mainly of vibrational data analysis. A new diagnostic tool in the field of bearing damage that has been recently introduced is the MEPA-10A Shock Pulse Meter. The principle of operation of this unit, is that, a damaged bearing in a machine generates mechanical shocks, which cause brief, high frequency vibrations to emanate from the point of impact. This pulse of energy is governed by the speed of sound in the structure material. It is attenuated at each mechanical interface and decays in amplitude in proportion to the distance and damping characteristics of the material through which it is travelling. An accelerometer is used as the sensor and its output is fed into an amplifier tuned to the accelerometers resonant frequency. After signal processing, the output is displayed on a meter having a 20,000:1 dynamic range, the meter displays shock pulse rate of occurance and the amplitude it is then possible to plot a curve of pulse rate versus the pulse amplitude, which is a revealing measure of bearing condition.

Because of the successful results obtained in detecting rolling bearing damage SKF Industries was contracted by Parks College of St. Louis University to establish the feasibility of, and determine a diagnostic approach for, the use of mechanical shock emissions to determine the condition of gears in an operating helicopter gear box. The tests were conducted on three UH-1 42° gear boxes. Each gear box was tested on an SKF test fixture which had been suitably modified for this series of tests. The fixture is shown in Enclosure1. As shown, the drive motor is belt coupled to

106

pulleys. These pulleys were changed to vary the gear box speed. The input quill is coupled to this pulley and is driven by it. The output quill is connected to a hydraulic pump which served to dissipate the energy transmitted, and whose pressure, and therefore whose load, can be varied with a manually operated valve.

The gear boxes were driven initially by a 15 horsepower induction motor into an IMO 3D hydraulic pump (with 156 rotor). The gear boxes tested were operated at speeds of 3560 RPM and 1500 RPM. These speeds were held to within 2% between tests. At each speed two different loads were applied. Early test data indicated that a greater load was desirable to more nearly approximate flight loads, and so an IMO A6D pump (with 137 rotor) and a 50 horsepower induction motor were installed on the fixture. This increased the drive and load of the test rig to 34 horsepower.

Enclosure 2 shows a curve of oil viscosity as a function of temperature for the oil used in both pumps during testing. Enclosure 3 relates oil viscosity to horsepower as a function of the pump pressure for the IMO 3D pump while Enclosure 4 does this for the IMO A6D pump.

Thus by controlling pump pressure and monitoring oil temperature the gear box applied load was determined.

II. Details

II a. Shock Pulse Tests at Low Loads

The first step in the program was to establish optimum sensor locations for detecting gear damage. After examination of the gear box drawing, four positions were chosen. Data obtained from these points however was not sufficiently different to clearly indicate one location as superior. Consequently because of the theory of shock pulse operation a location was selected which had a direct mechanical path to the gear mesh. A spot located over the roller bearing on the input quill was selected. An aluminum block conforming to the shape of the housing was fabricated and after the paint was removed from that area of the gear box housing, the block was bonded to the housing. A second or backup spot was selected on the base opposite to the oil level gage. This location was selected because the gear box structure in this location was suitable for mounting an accelerometer and there was also a direct mechanical path to the gear mesh. Enclosure 5 shows the sensor locations.

Gear box S/N A13-830 was the first gear box tested. Enclosures 6 and 7 depict the base line data obtained for this gear box. As can be seen from the data the shock level increased mainly as a function of speed and not of load. Damaged gears with pitting damage were then installed into this gearbox. Enclosure 8 shows a picture of these gears prior to their insertion into the gear box. The upper picture is of the output gear, which has pieces of gear teeth missing probably due to earlier gear failure in another gear box. These gears had however, not been previously run as a set in this gear box. Enclosures 9 and 10 show the data obtained with these damaged gears installed. Position 2 data at 1480 RPM shows higher shock levels with the damaged gears than with the undamaged ones, but at the higher speed it is less.

II b. Shock Pulse Tests at Higher Loads

Since these damaged gears had not operated as a set previously, the possibility exists that the damaged areas were not contacting during operation. In addition, the load placed on the gear box was much less than the actual load presented to the gear box in a helicopter. To provide more representative load the previously discussed motor and pump change was made. The same speeds were maintained but higher loads could be transmitted. Tests at the new loads indicated a small increase in the shock level for a previously tested gear box for both position 1 and position 2, as can be seen in Enclosure 11. When comparing this data with that for undamaged gears, at the same load and speed, however, no large shock level differences are evident.

At a later stage in the program a third set of gears was installed in this same gear box. These gears were damaged. The damage is shown in Enclosure 12. Data obtained from these gears is shown in Enclosures 13 and 14.

There is little difference between the curves shown in Enclosure 11 through 14, and those shown in Enclosures 6 and 7. One event of significance that occurred early in testing at 3540 RPM at 13 HP load was a sharp increase in shock level for a period of about 2 minutes. The data obtained during this time period is shown in Enclosure 14. This gear box was run for an additional two hours in anticipation of this event recurring. It did not. A post test examination of the oil in the gear box showed fine metal particles throughout the oil.

The second gear box for which base line information was taken was S/N B13-1561. This data is shown in Enclosures 15 and 16. It is similar to the baseline data obtained from gearbox S/N A13-830 shown in Enclosures 6 and 7 with the only difference being that the position 2 shock level data at the higher speed was about one half that of the first gear box baseline value.

This second gear box SN B15-1561 was also retested with higher loads. Enclosure 17 shows the data obtained at 3540 RPM. There was a slight change in shock level data compared to that in Enclosure 16 and this was a decrease in position 2 readings. Because the data showed no marked change with these higher loads at 3540 RPM, the lower speed runs were not repeated.

This gear box was then removed from the fixture and the gears taken out. They are shown in Enclosure 18. An artificial damage was then put on the output quill gear with a hand grinder, and the two gears reinstalled in the gear box.

After the gear box was remounted in the fixture, data was taken at 1520 RPM, and is shown in Enclosure 19. Position 1 data indicates a high rate of shocks at low shock levels. This is indicative of solid particulate matter in the lubricant.

Position 2 data was slightly lower in shock level than normal for this speed. To assure the reliability of data obtained from position 2 (verify that bonding the block did not adversely affect the test) a hole was drilled and tapped to mount the accelerometer block directly to the gear box thereby eliminating the potential interface effect of the glue. Data was obtained at the higher speed (3540 RPM), the hole was drilled and tapped and the test repeated. This repeat data is shown for comparison in Enclosure 20. There was a slight increase in both rate and level with the new accelerometer mounting.

The difference lies within the normal variation of readings from run to run, however.

Enclosure 21 shows the shock data obtained for the artificially damaged gear implant at a speed of 3540 RPM. Position 1 data has changed back to the more usual curve shape obtained at this speed on the other gear boxes.

At this point the gear box was operated for an extended period of time and data taken periodically to monitor the trend or growth with time. Enclosure 22 shows data acquired after running for 5, 10, 30 and 50 minutes respectively. There was a 4 to 1 growth in shock level which normally indicates damage growth. The unit was again run for an additional hour the next day, however, the curve shape did not change from that shown for 50 minutes in Enclosure 22. Visual examination of the gear box oil showed fine metal particles. The most likely source of these metallic particles is the gear which ha been artificially damaged. Because of the roughness at the edges of the artificially damaged area of the gear metal burrs could break off quite easily.

Next an input quill assembly with artificial damage on the gear was implanted in this same gear box. The damage had been put in the gear with a carbide scribe. Burring that occurred during the scribing was not removed. A photo of this gear is shown in Enclosure 23. The output quill in which the gear had been previously artificially damaged by the hand grinder was not removed. Initial readings showed a shock level of about 9 at position 2. This quickly changed to about 25 within a minute or two after the gear box was started and took the shape of the curve shown in Enclosure 24. Enclosure 25 shows data obtained at position 1 while Enclosure 26 shows data obtained using a Parks College type VD-3 accelerometer holder supplied by Parks College. The holder was mounted to a bolt on the input quill housing. There was some variation in shock rate with time as can be seen in the three enclosures. This type of variation had not been observed in the past. Also there were occasional but regular rate spikes observed which gave readings of up to 2000. Increases in the rate of small shocks is characteristic of particulate contaminant in the lubricant passing through the bearings.

Upon request by Parks College an "unknown condition" input quill assembly supplied by Parks College was implanted in the gear box and data again taken. This time the rate readings were also variant. The data is shown in Enclosures 27, 28, and 29. The readings obtained also showed extremely high shock level indicative of bearing damage.

This implant rather than having a gear damage had a damaged bearing and this is shown in Enclosure 30. The ability of the MEPA-10A to isolate bearing damage was once again demonstrated.

A third gear box was tested at low and high loads and speeds.

Only base line data was obtained, however, and it is shown in Enclosure 31 and 32.

II c. Vibration Measurement

In addition to the above testing, single axis vibration measurements were also made. This was done using an SKF Industries MEB-17A Vibration Amplifier, which determines vibrational velocity from an accelerometer input signal. This unit has three frequency bands (50 to 300 HZ, 300 to 1800 HZ, and 1800 to 10,000 HZ) and is used for vibration testing of bearings at SKF. The sensor used was the accelerometer located at position 2. The data obtained is shown in Enclosure 33. It is evident that vibration velocity levels are not a conclusive measure of gear damage. Although there appears to be some correlation between damage and vibration readings, this is true only for certain damaged gears and not for all. At the same time a tape recording of the vibrational velocity signal output was made. This was later reduced and analyzed on a B&K 1/3 Octave Frequency Spectrum Analyzer.

The B&K traces are shown in Enclosures 34 and 35. As can be seen from the data the gear mesh frequency predominates, and damage gears do not show marked differences (increase in amplitude) as compared to undamaged gears.

CONCLUSIONS

Three gear boxes with several different types of gear damage have been run at two different loads and at two speeds. From the data obtained during testing, the following has been determined:

1. The MEPA-10A detects gear damage in an operating gear box in a secondary manner. The metal chips and particles that are the products of the mesh of damaged gear teeth tend to pass through the bearings as the oil in the gear box circulates.

2. The shock pulse technique has again proven successful in isolating a damaged bearing in a gear box as shown in Enclosures 27, 28, 29 and 30. This coupled with the ability to detect incipient gear failure by the effect of the associated particulate contaminant in the lubricant being measured by the MEPA-10A establishes the shock pulse technique as a viable total gear box condition monitoring technique.

3. Standard shock pulse analysis techniques using the MEPA-10A (shock emission profile) do not appear conclusively to provide a direct measurement of gear damage with the sample evaluated in testing. The sample consists of natural and artificial damages implanted but without certainty as to the degree and severity of damage encounter in the gear mesh.

4. Vibrational velocity monitors analyzing the signal in three, two and one-half octave bands, or one-third octave analysis, do not

provide any consistent indication of the existence of gear damage. The undamaged gear set was characterized by higher vibration in fact.

RECOMMENDATIONS

While the test program results indicate the capability of the shock pulse technique to detect gear damage change by measurement of the effect of gear damage debris on the shock pulse rate measured, certainty of correlation of damage size or growth rate to the measurements were not established. The program scope did not contain this task, but rather directed that correlation of shock level and gear damage be determined.

1. To fully establish that shock pulse measurement of lubricant debris from gear damage (and as a matter of fact gear wear) tracks damage condition from incipient through advanced stages requires the following effort:

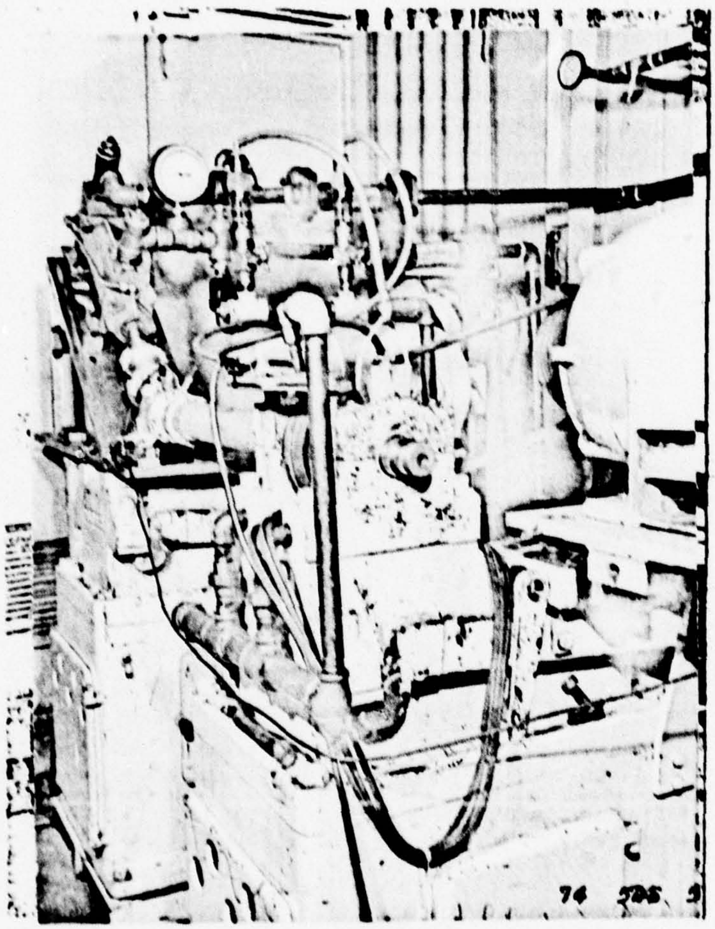
a) Modify the existing test fixture to permit higher gear box loading. Conduct gear endurance tests to obtain naturally caused damage and allow damage to grow.

b) Measure the shock emission profiles effect of the gear emitted debris and correlate through periodic gear box examination to level of gear damage and wear present, and with oil debris content analysis.

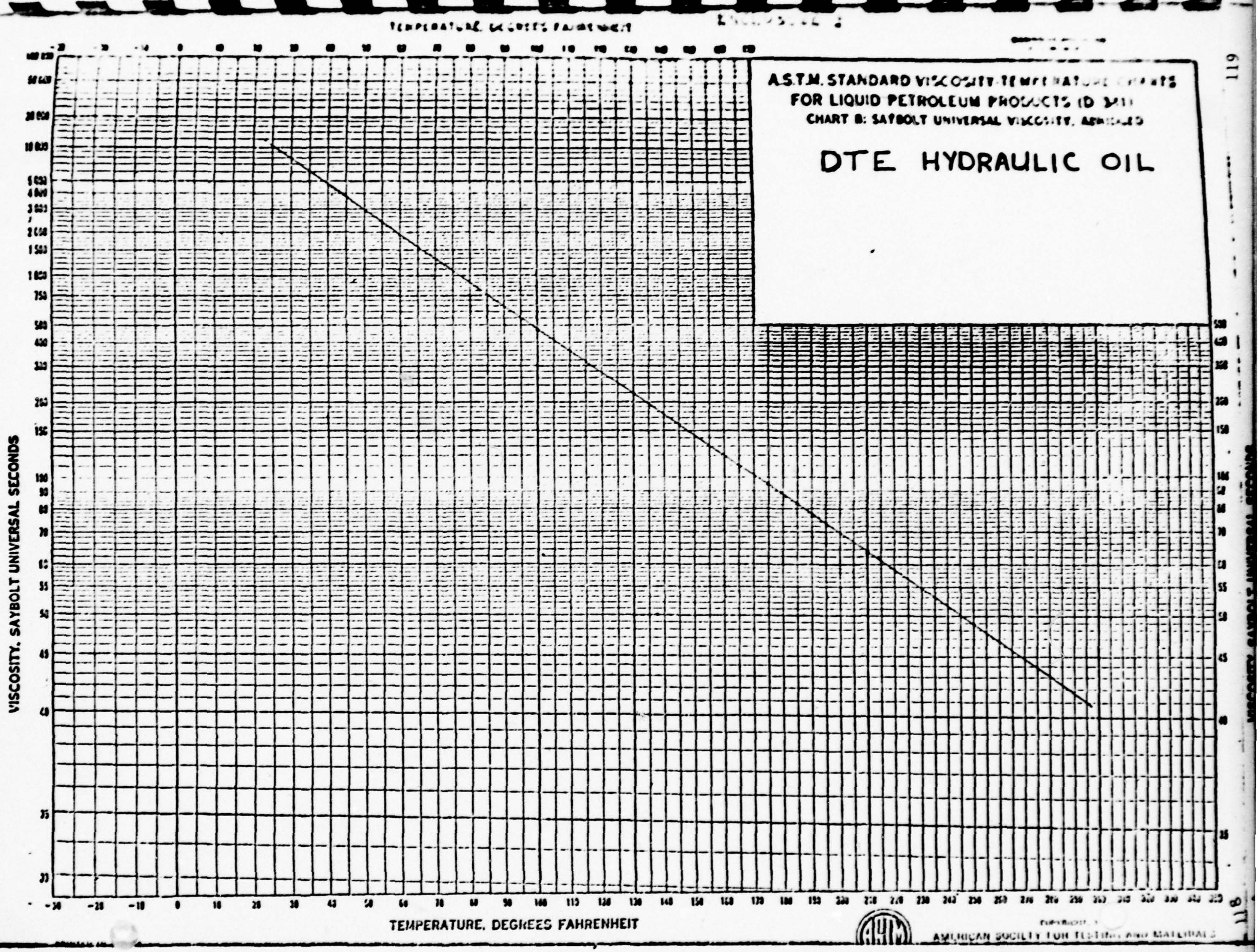
2. A second area where effort can be applied is development of more sophisticated shock pulse analysis techniques to examine the emitted shocks between the main gear mesh shocks.

It is apparent from the B&K traces that the amplitude of vibration emitted at the gear mesh frequency is very high, due to the meshing impact. The damaged areas come in contact only as the teeth slide across one another. It would appear that the impact of the damage as compared to the impact of the teeth mesh is quite small. The shock pulses emitted by the damage also would occur at a higher frequency. Since the MEPA-10A has proven so successful in the measurement of bearing damage, modification of the electronics should be considered to investigate the shock pulses emitted in the time segment between the meshing of teeth, as a measure of gear damage severity.

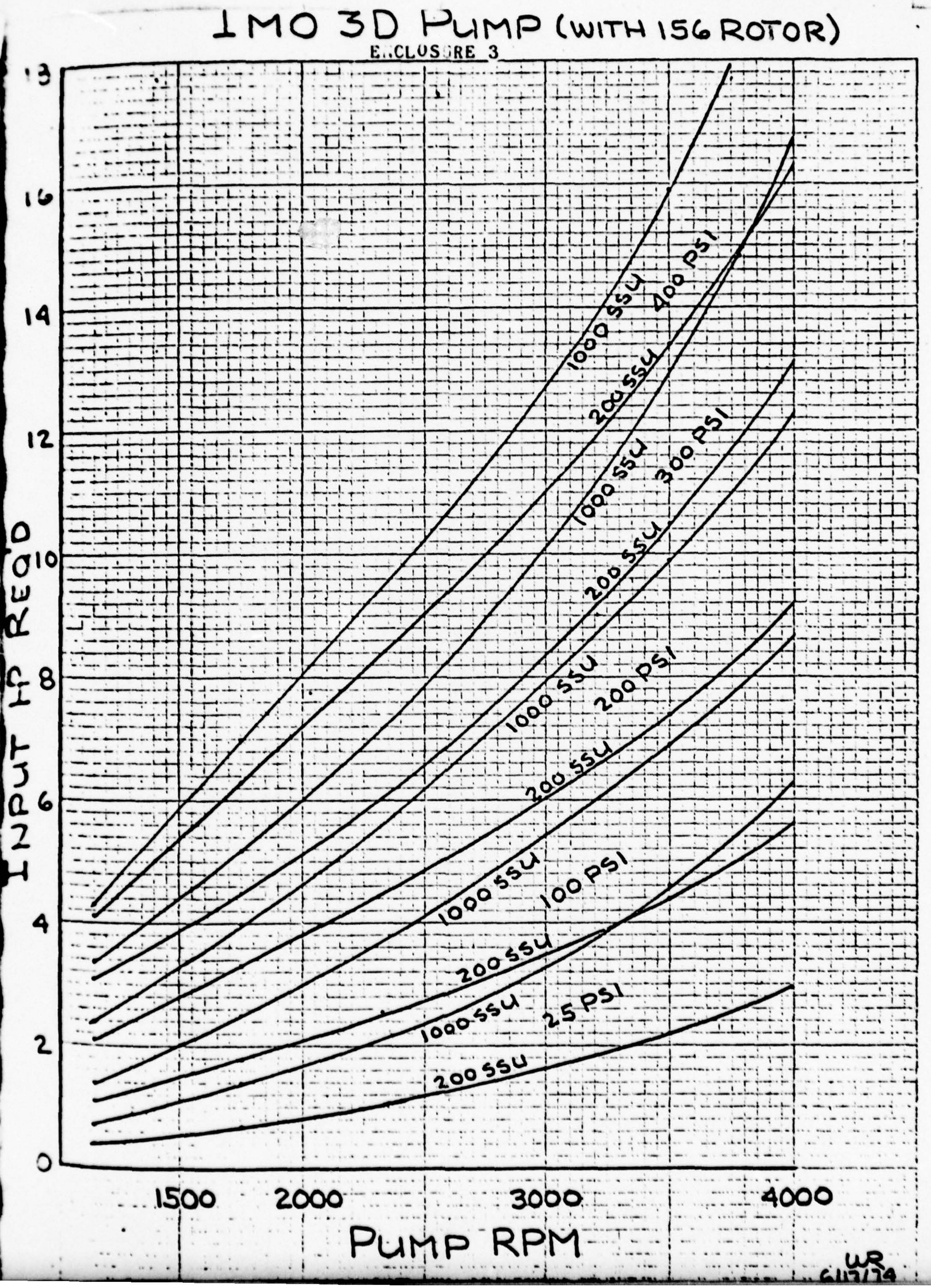
ENCLOSURE 1



TEST FIXTURE


A.S.T.M. STANDARD VISCOSITY-TEMPERATURE CHARTS
FOR LIQUID PETROLEUM PRODUCTS (D 341)
CHART B: SAYBOLT UNIVERSAL VISCOSITY, ABRIDGED
DTE HYDRAULIC OIL
VISCOSITY, SAYBOLT UNIVERSAL SECONDS
TEMPERATURE, DEGREES FAHRENHEIT
AMERICAN SOCIETY FOR TESTING AND MATERIALS

ENCLOSURE 3

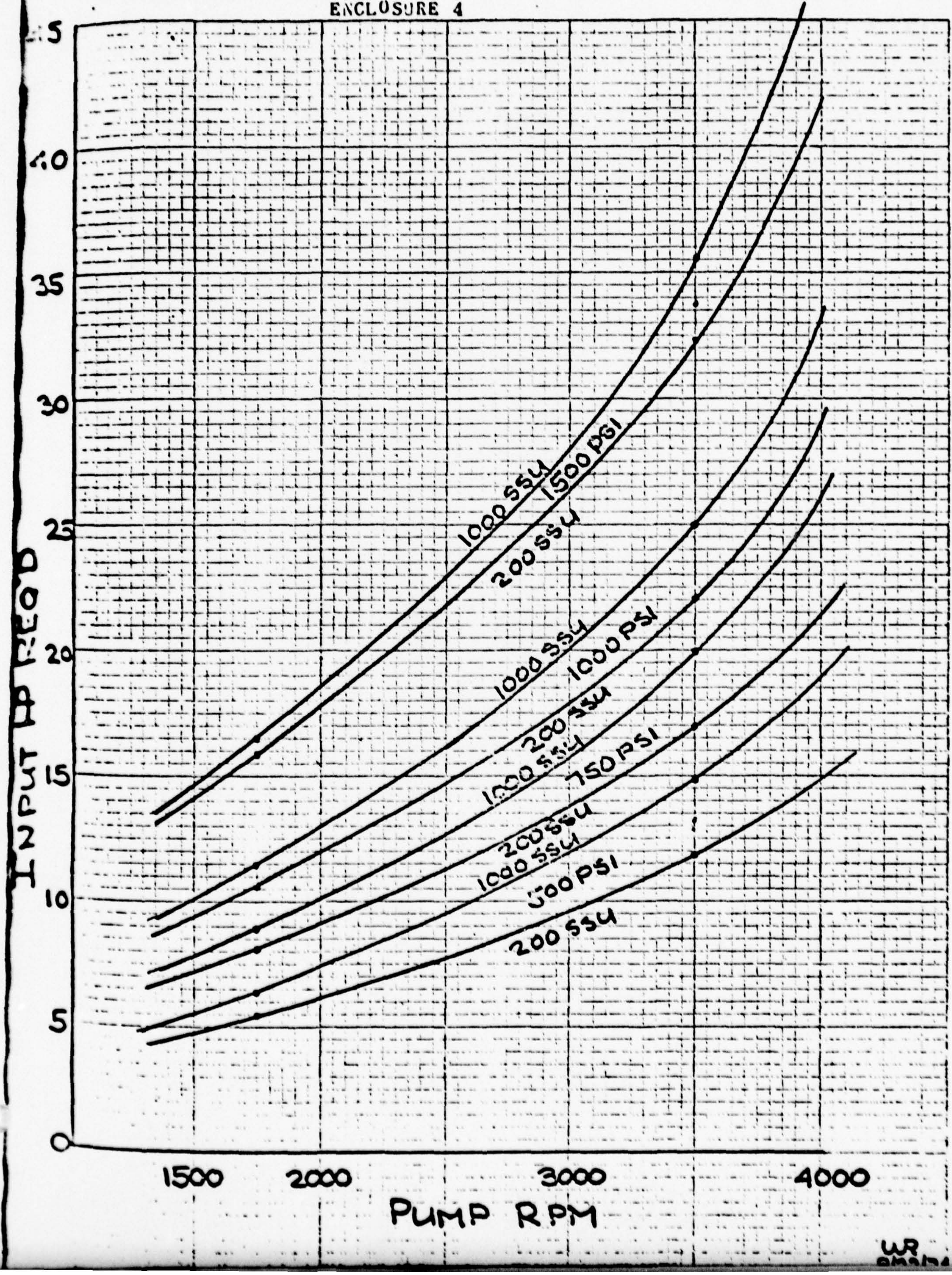


120

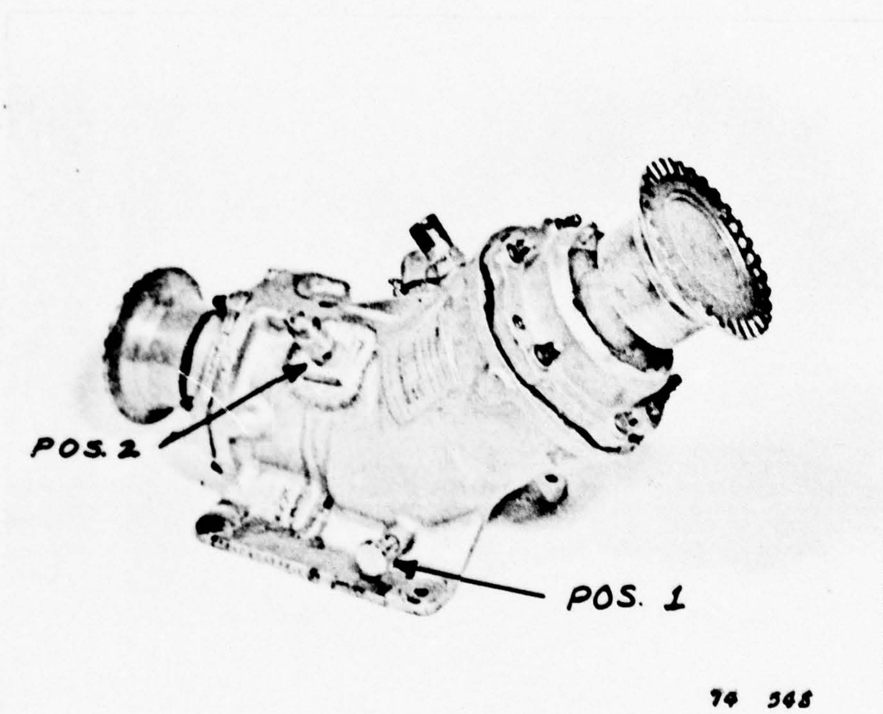
119

IMO A6D PUMP (WITH 137 ROTOR)

ENCLOSURE 4



ENCLOSURE 5

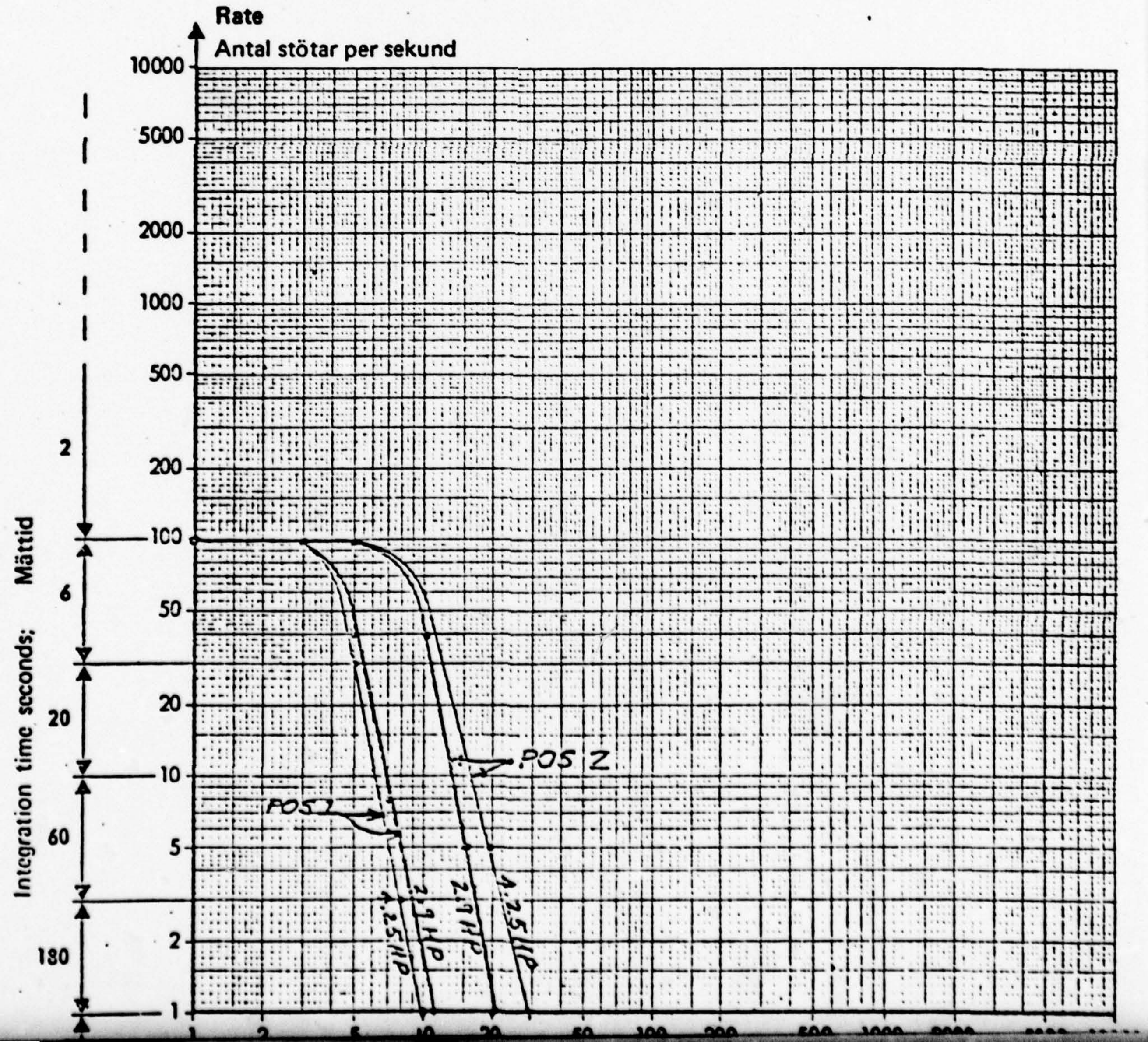


42° Gear Box

SKF SHOCK PULSE METER MEPA 10 A	Rate measurement of shocks per second Förekomstfrekvens	

S/N A13-830
BASE LINE DATA
SPEED: 1480 RPM
AMBIENT: 82°F
GEAR BOX TEMP: 103°F

ENCLOSURE 6



SKF

SHOCK PULSE METER

MEPA 10 A

Rate measurement of shocks per second

Förekomstfrekvens

S/N A13-830

BASELINE DATA

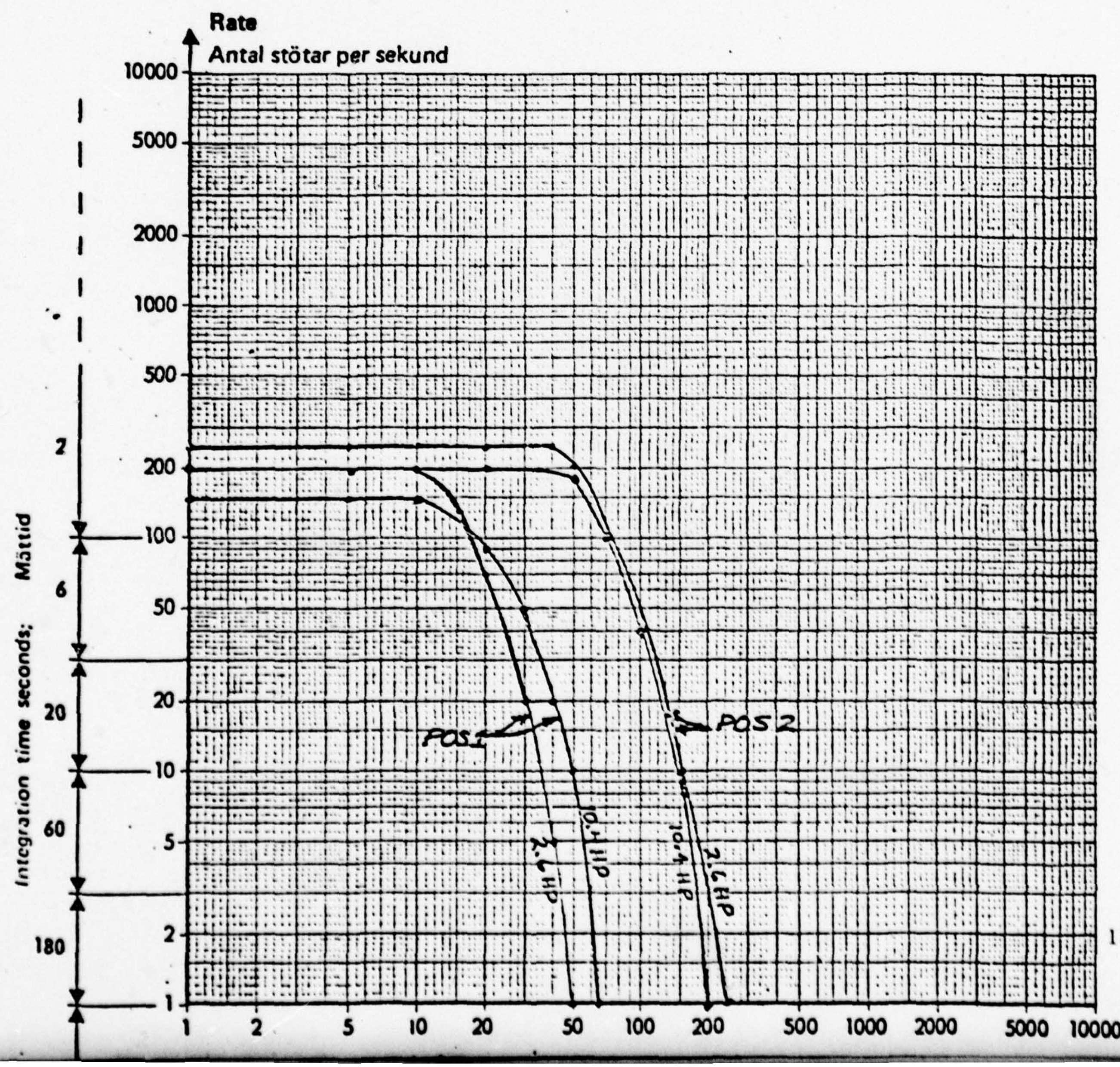
SPEED: 3560 RPM

AMBIENT: 85°F

GEAR BOX TEMP: 138°F at 2.6HP

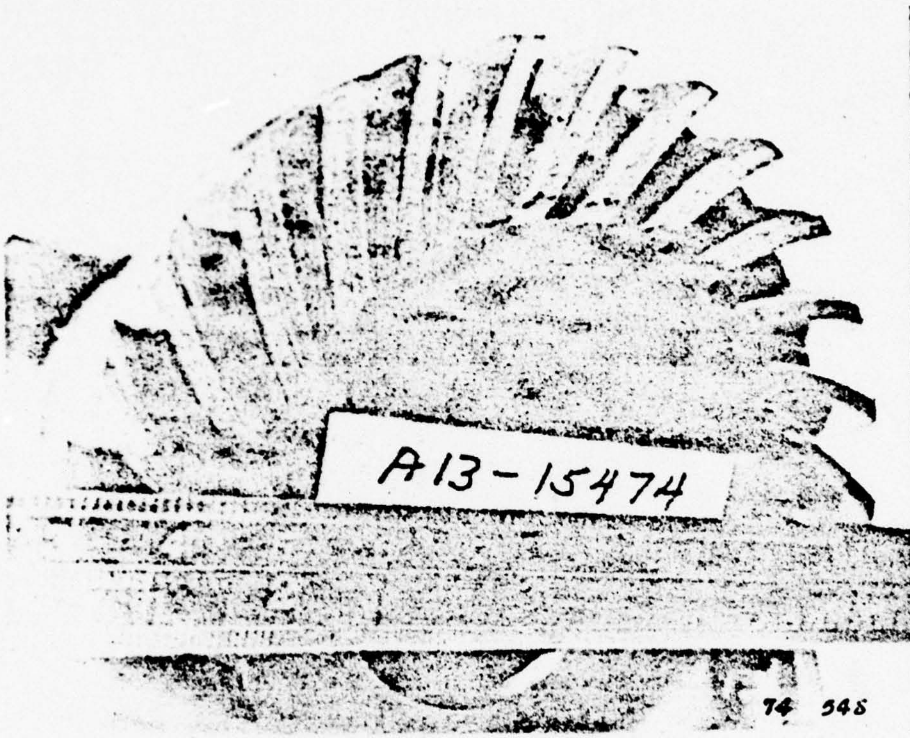
150°F at 10.4HP

ENCLOSURE 7

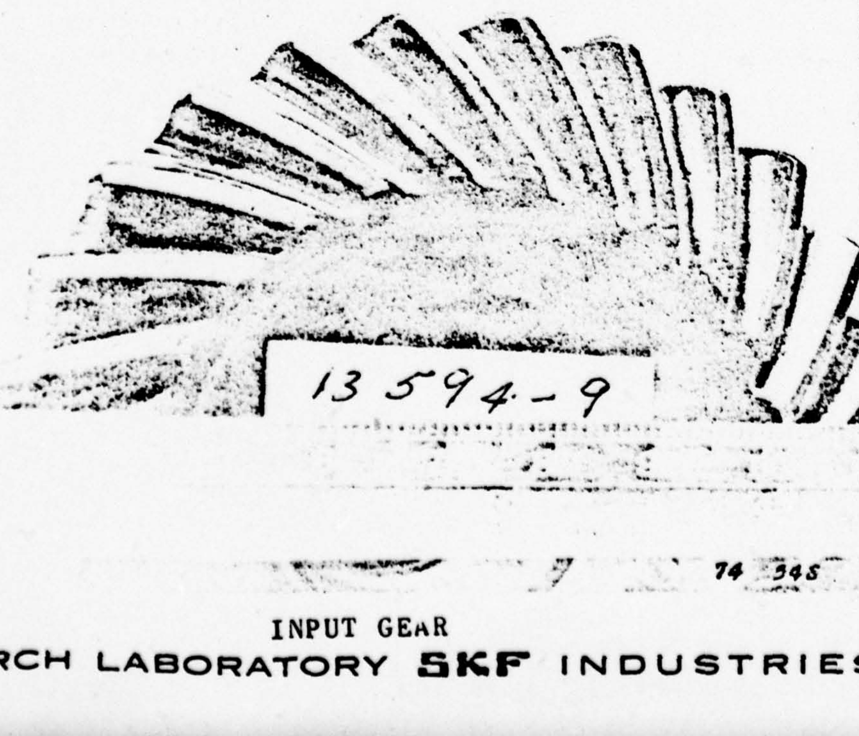


123

ENCLOSURE 8



OUTPUT GEAR

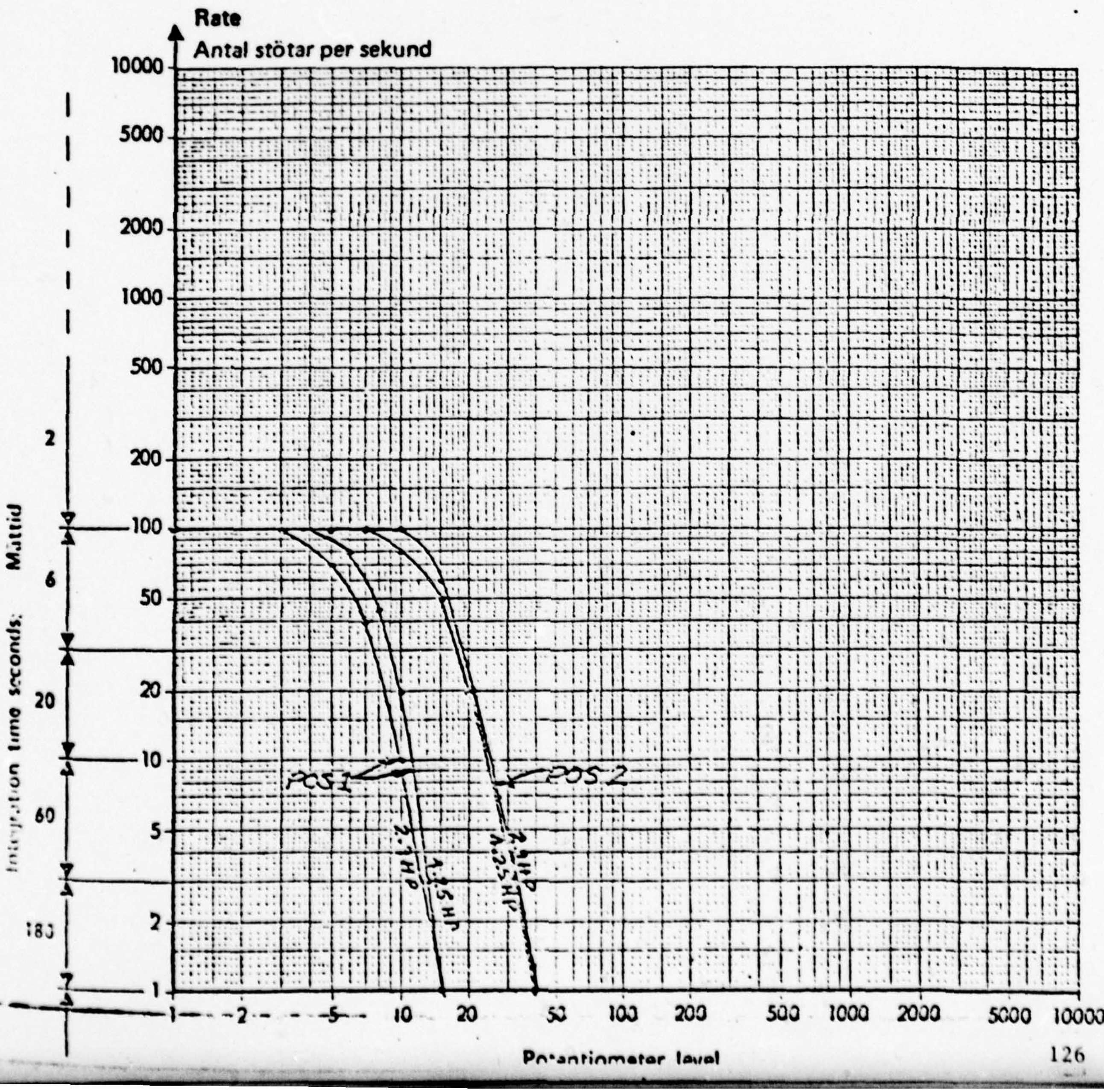


INPUT GEAR

SKF SHOCK PULSE METER **MEPA 10 A**	Rate measurement of shocks per second Förekomstfrekvens	

S/N A13-830
HEAVILY DAMAGED GEARS
SPEED: 1480 RPM
AMBIENT: 72°F
GEAR BOX TEMP: 100°F

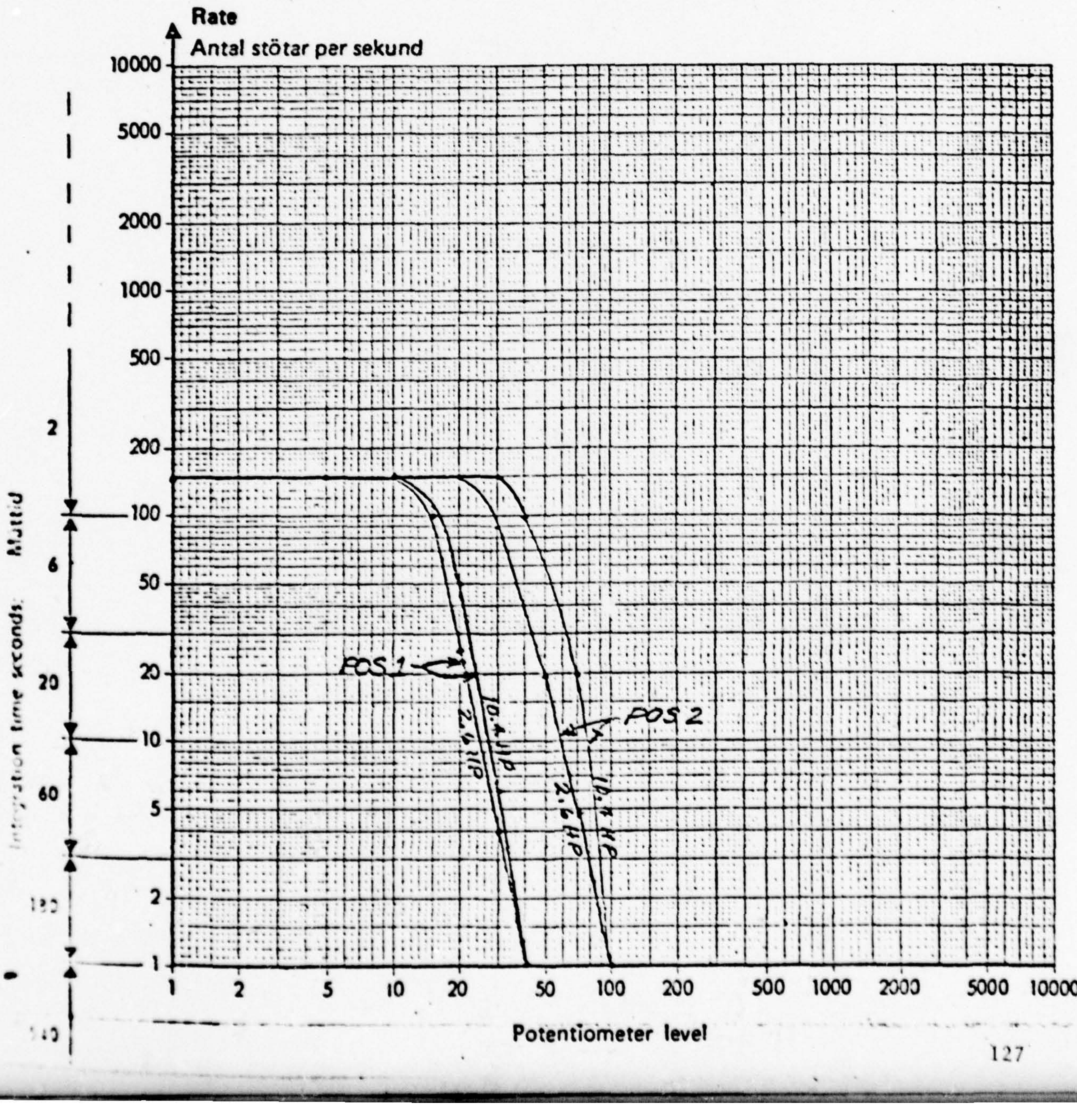
ENCLOSURE 9



SHOCK PULSE METER MEPA 10 A	Forekomstfrekvens	

S/N A13-830
HEAVILY DAMAGED GEARS
SPEED: 3580 RPM
AMBIENT: 76°F
GEAR BOX TEMP: 140°F at 10.4 HP
128°F at 2.6 HP

ENCLOSURE 10



SKF SHOCK PULSE METER

MEPA 10 A

Rate measurement of shocks per second

Förekomstfrekvens

S/N A13-830.

HEAVILY DAMAGED GEARS

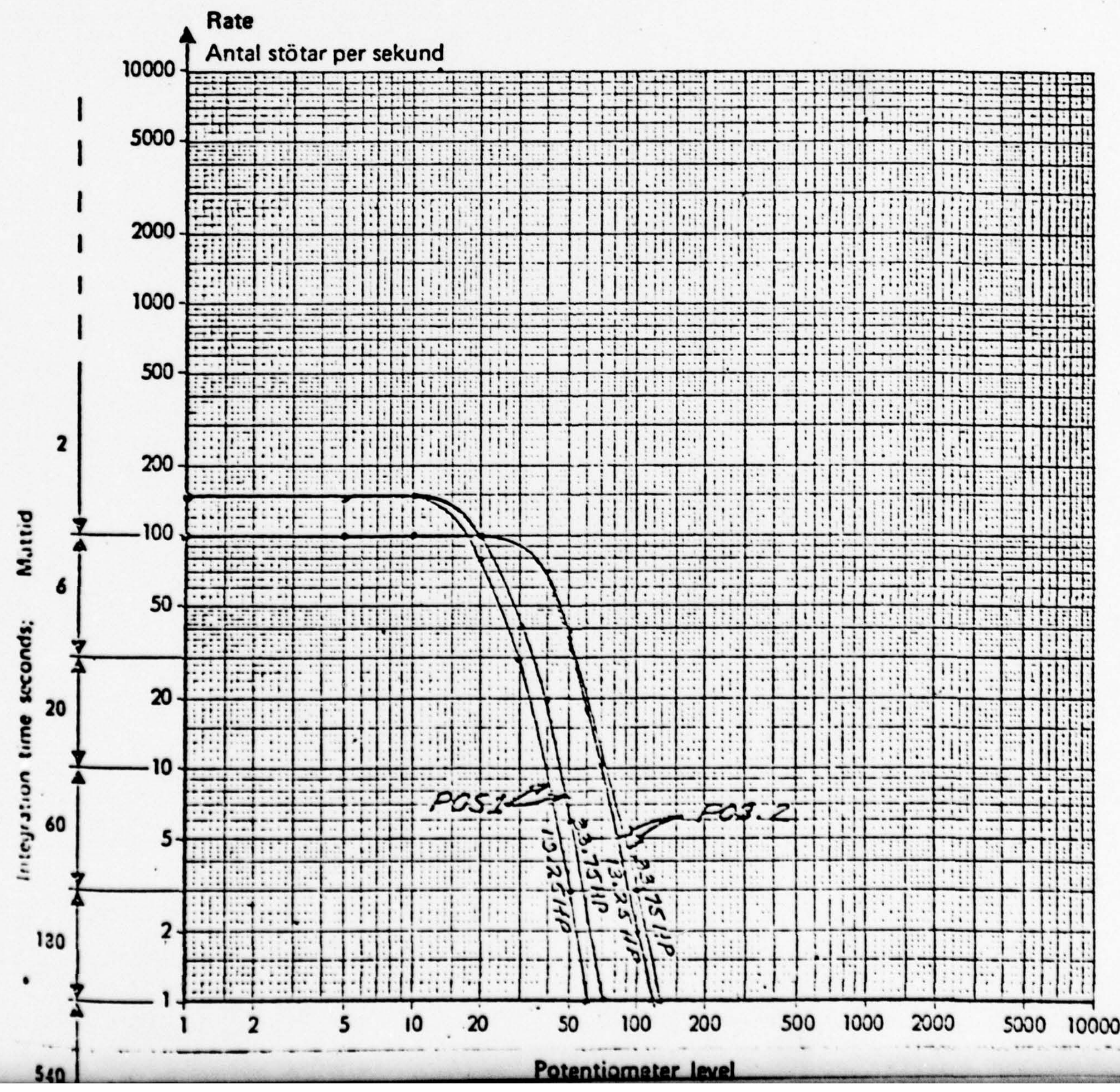
SPEED: 3540 RPM

AMBIENT: 86° F

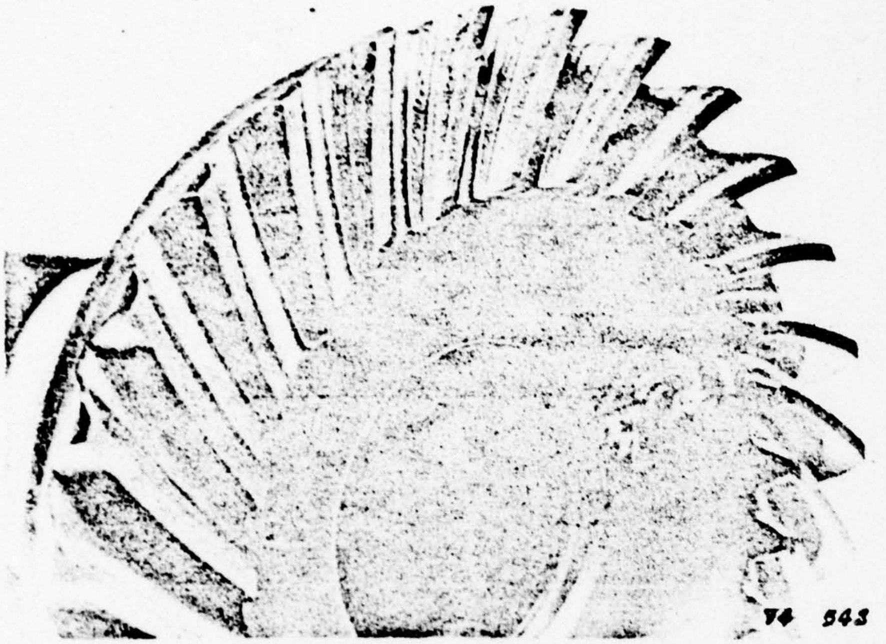
GEAR BOX TEMP: 165°F at 33.75 HP

157°F at 13.25 HP

ENCLOSURE 11



ENCLOSURE 12



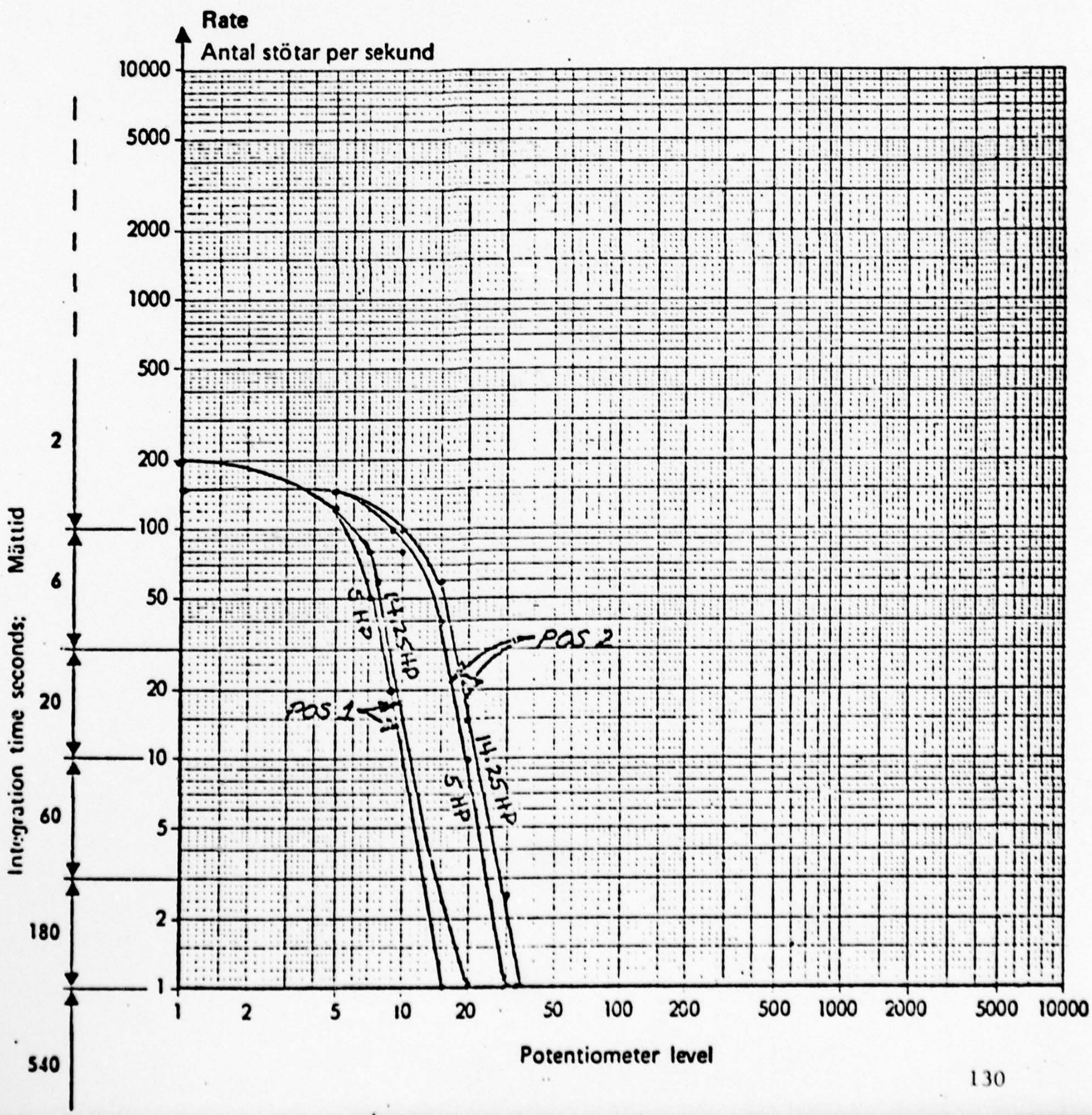
OUTPUT GEAR

INPUT GEAR

MEPA 10 A

S/N A13-830
DAMAGED GEARS (2nd SET)
SPEED: 1510 RPM
AMBIENT: 72 °F
GEAR BOX TEMP: 103°F at 14.25 HP
99°F at 5HP

ENCLOSURE 13



SKF SHOCK PULSE METER MEPA 10 A	Rate measurement of shocks per second Förekomstfrekvens	

S/N A13-830

DAMAGED GEARS (2ND SET)

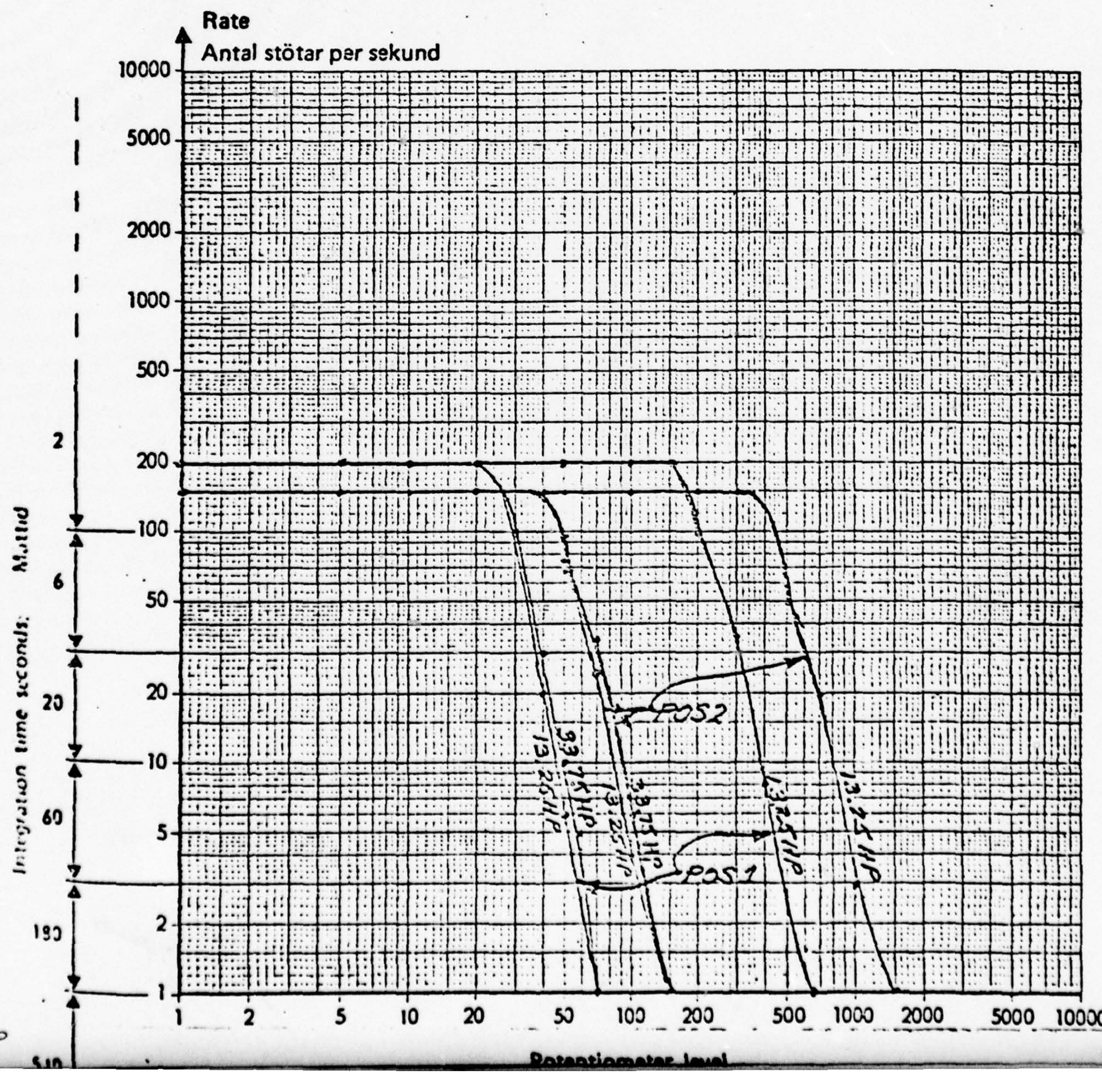
SPEED : 3540 RPM

AMBIENT: 82°F

GEAR BOX TEMP: 162°F at 33.75 HP

153°F at 13.25 HP

ENCLOSURE 14



130

SHOCK PULSE METER

MEPA 10 A

S/N B13-1561

BASELINE DATA

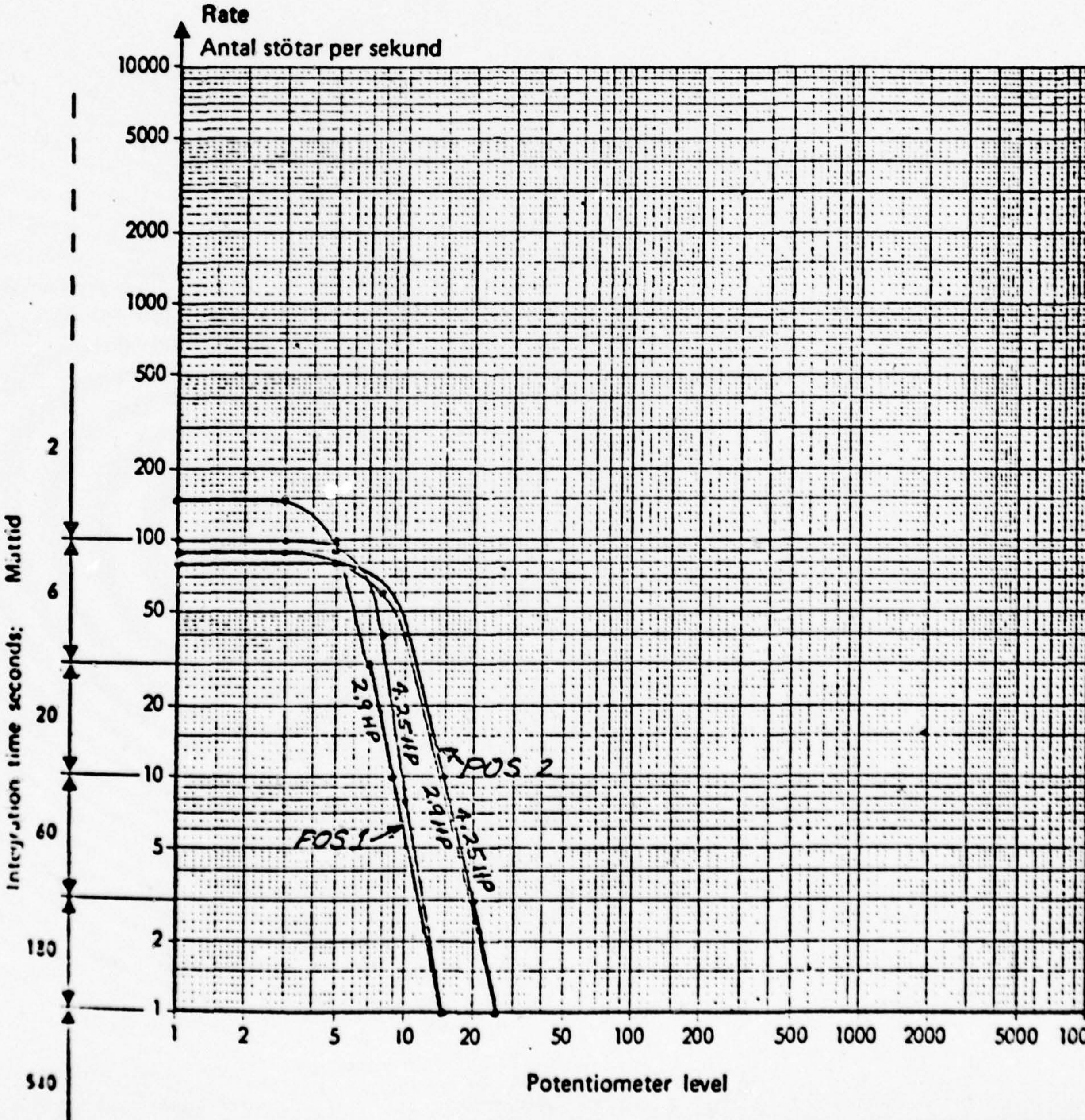
SPEED: 1490 RPM

AMBIENT: 85°F

GEAR BOX TEMP: 108°F at 4.25 HP

107°F at 2.9 HP

ENCLOSURE 15



131

MEPA 10 A

S/N B13-1561

BASELINE DATA

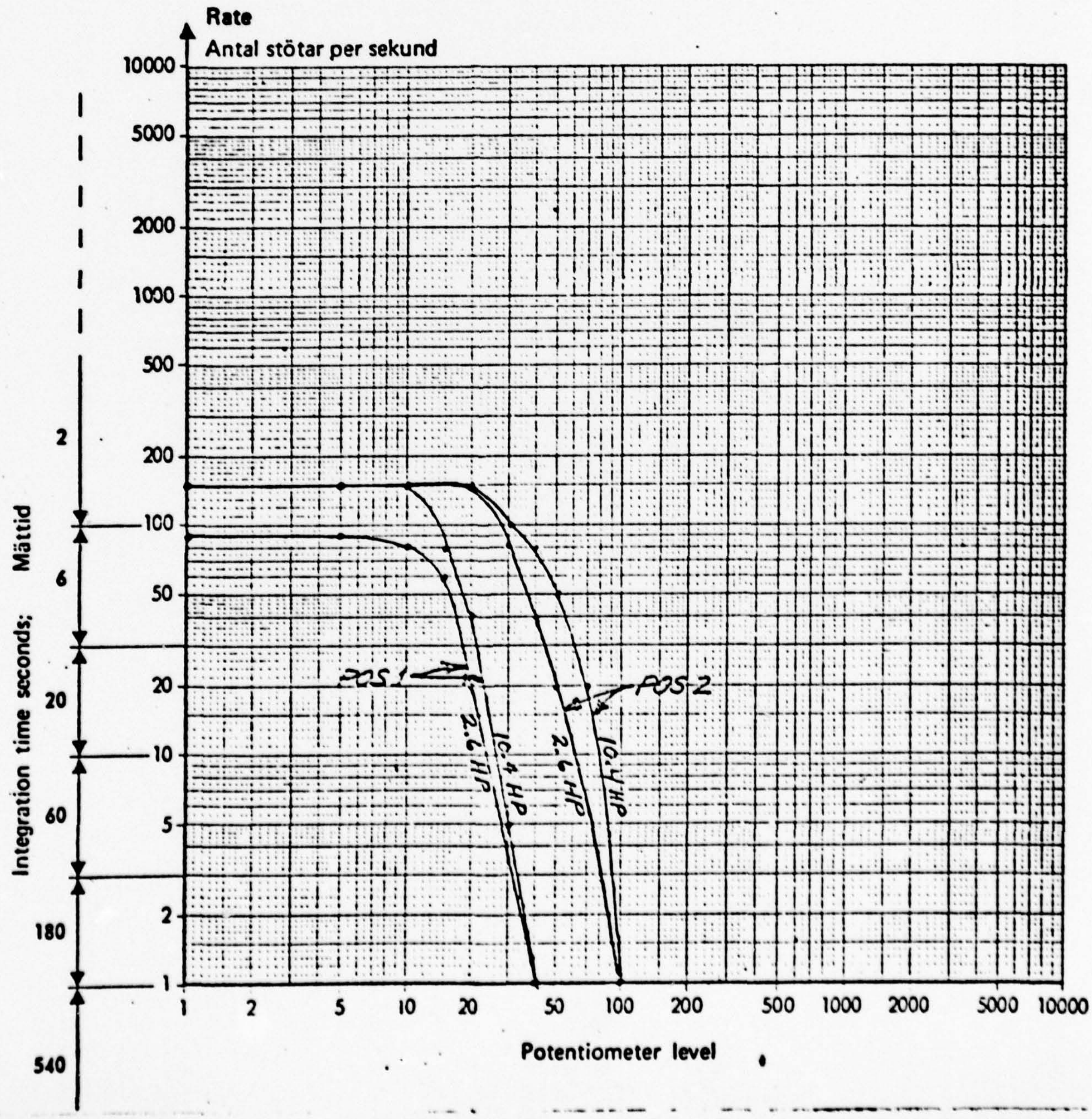
SPEED : 3580 RPM

AMBIENT: 75°F

GEAR BOX TEMP: 143°F at 10.4 HP

128°F at 2.6 HP

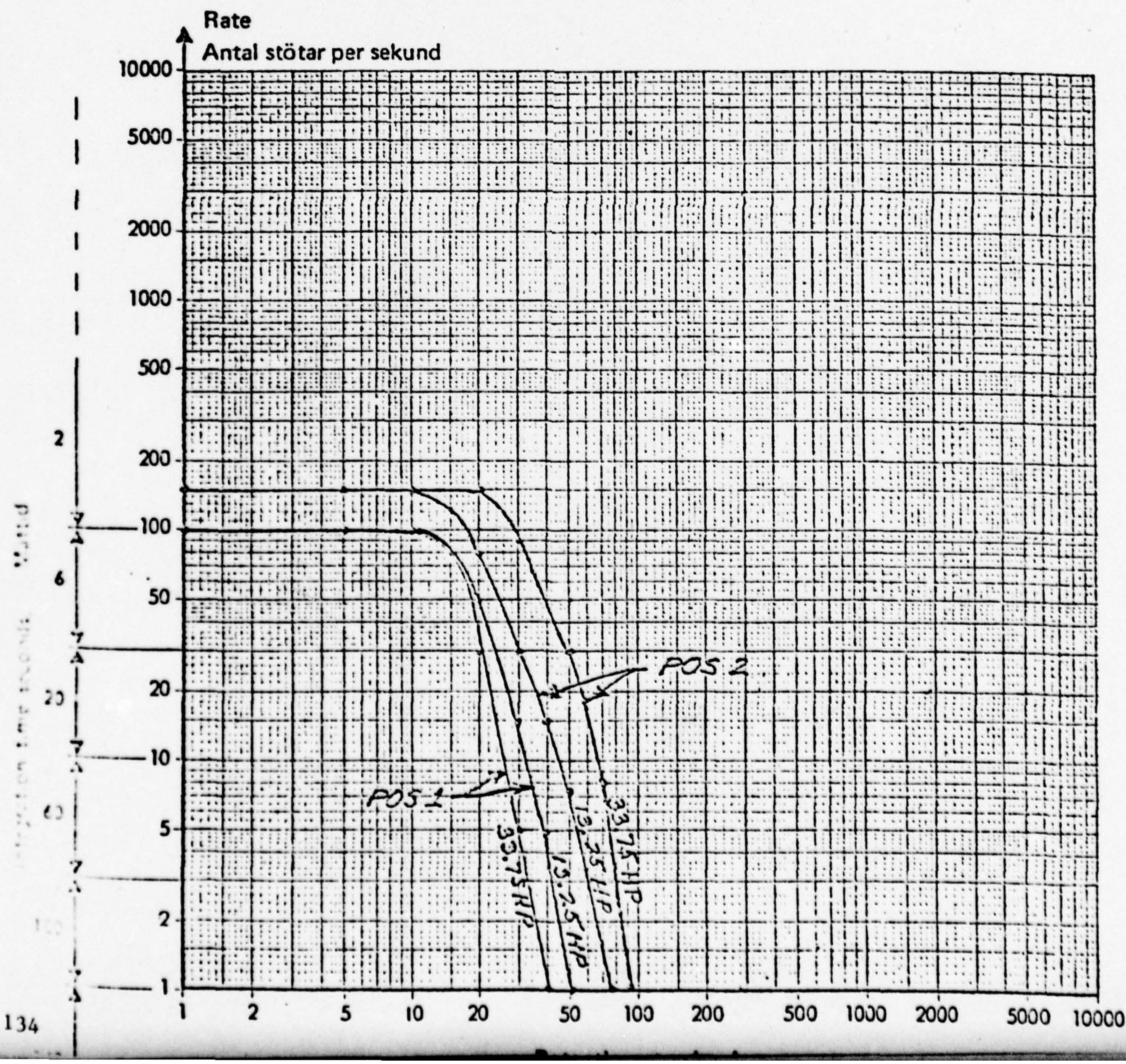
ENCLOSURE 16



SKF SHOCK PULSE METER MEPA 10 A	Rate measurement of shocks per second Förekomstfrekvens	

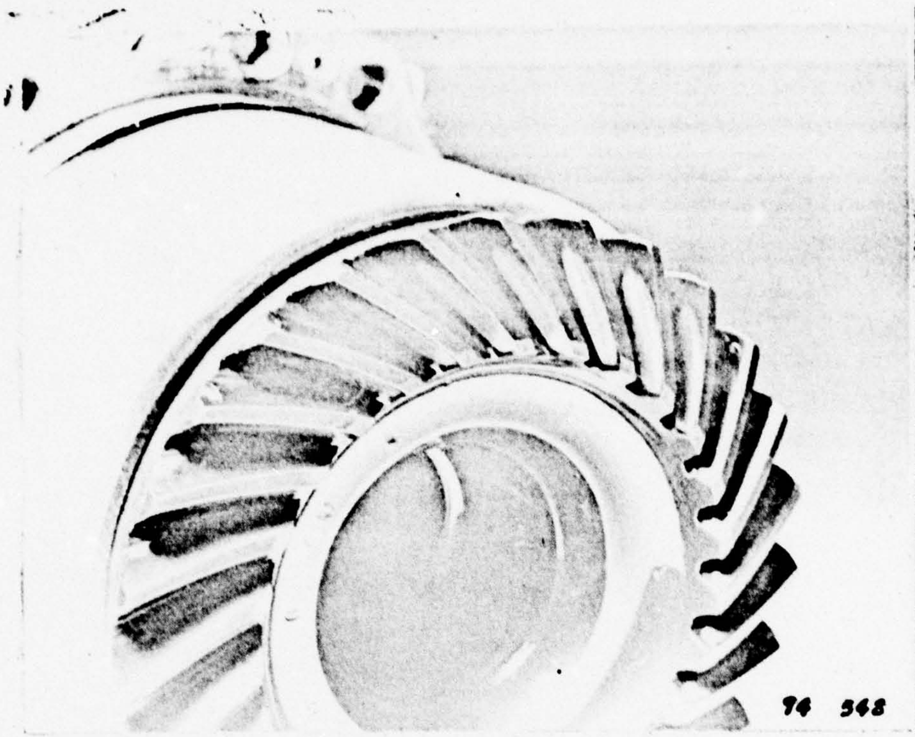
S/N B13-1561
BASELINE DATA
SPEED: 3540 RPM
AMBIENT: 86°F
GEAR BOX TEMP: 186°F at 33.75 HP
180°F at 13.25 HP

ENCLOSURE 17



133 134

ENCLOSURE 18



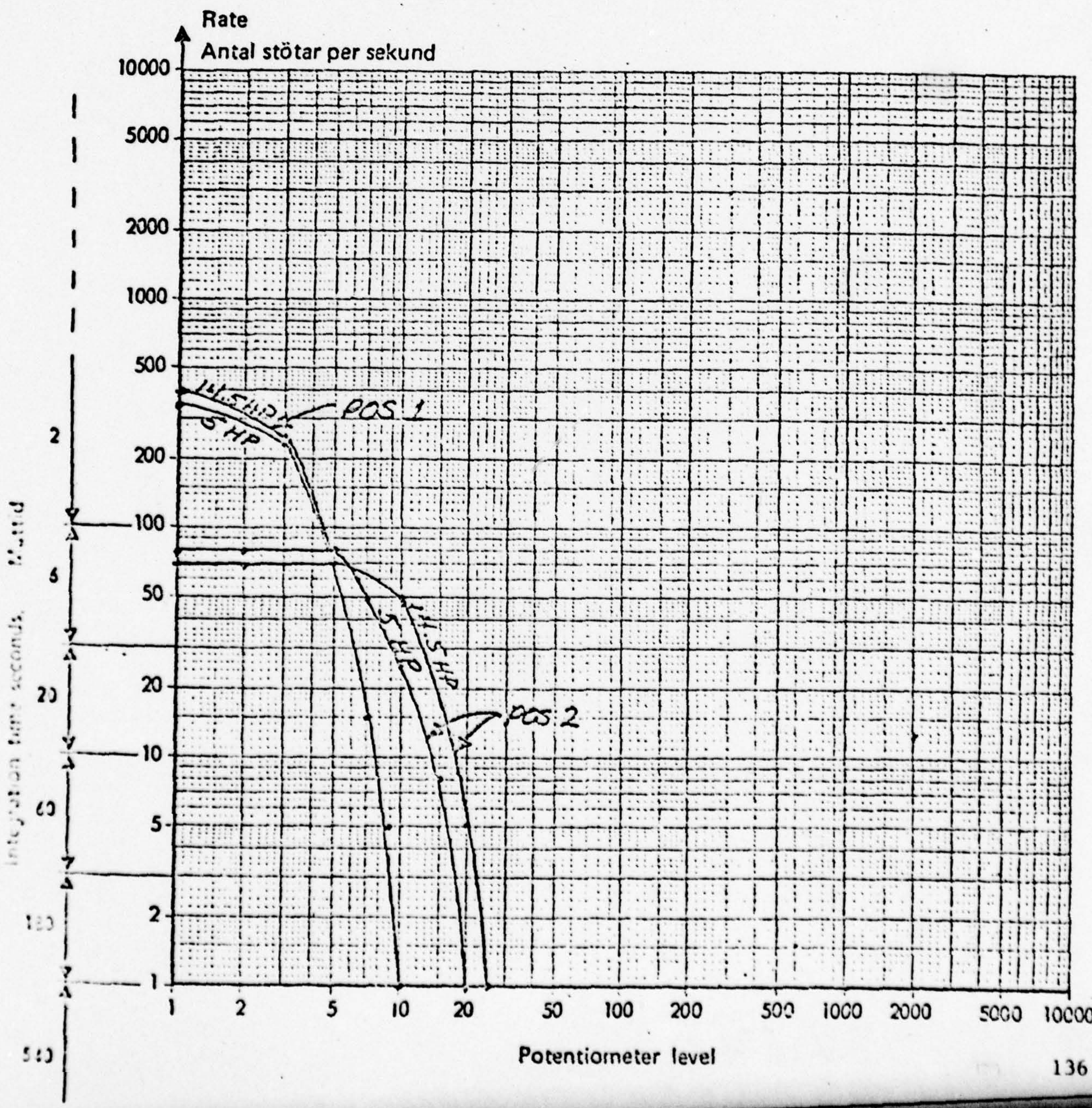
INPUT GEAR

OUTPUT GEAR

MEPA 10 A

S/N B13-1561
ARTIFICIALLY DAMAGED GEARS
SPEED: 1520 RPM
AMBIENT: 78°F
GEAR BOX TEMP: 107°F at 14.5 HP
105°F at 5 HP

ENCLOSURE 19



SPM

SHOCK PULSE METER

MEPA 10 A

Rate measurement of shocks per second

Förekomstfrekvens

S/N B13-1561

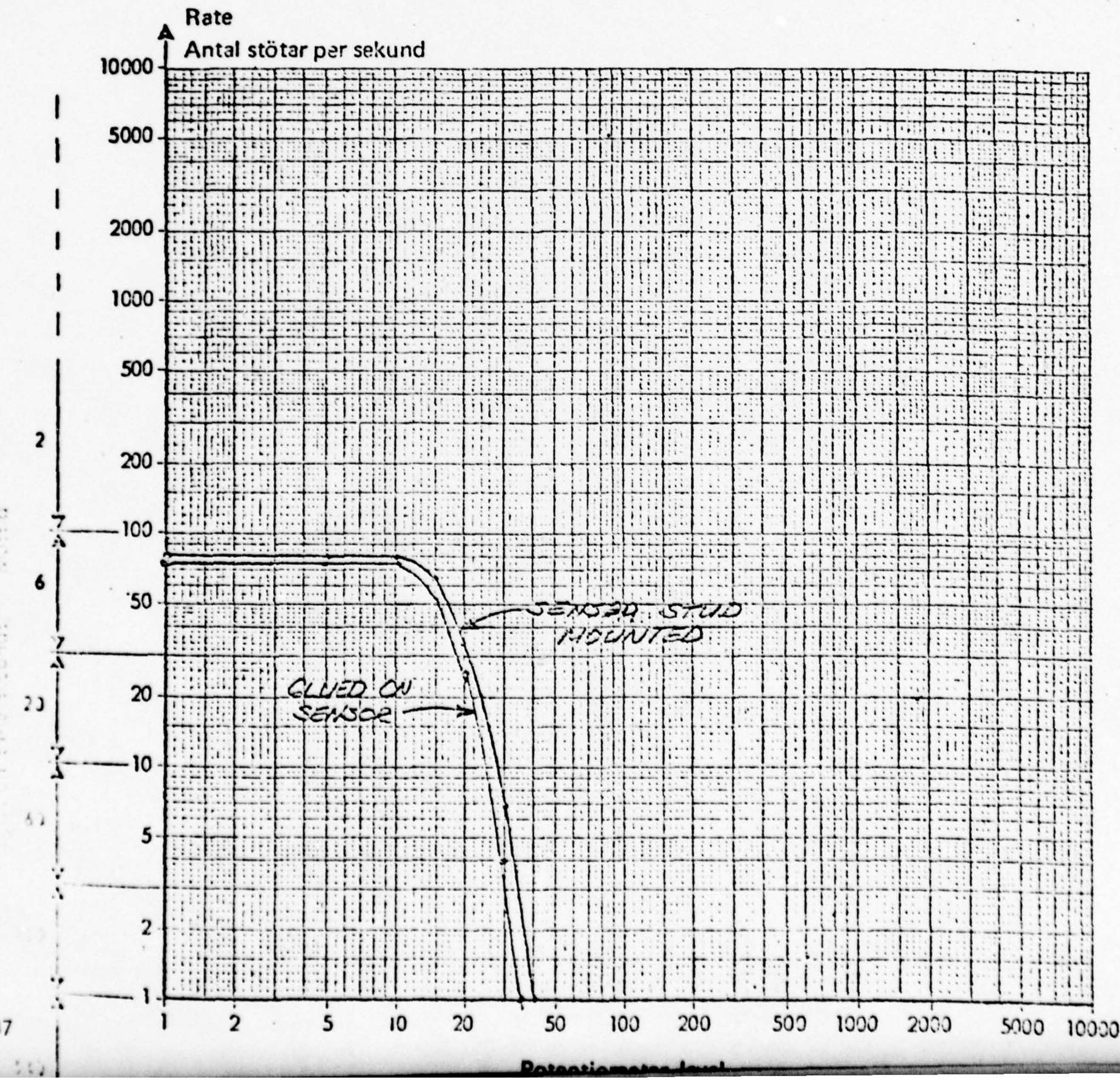
ARTIFICIALLY DAMAGED GEARS

SPEED: 3540 RPM

AMBIENT: 78°F

GEAR BOX TEMP: 108°F at 13.25 HP

ENCLOSURE 20



PULSE METER

EPA 10 A

Förekomstfrekvens

S/N B13-1561

ARTIFICIALLY DAMAGED GEARS

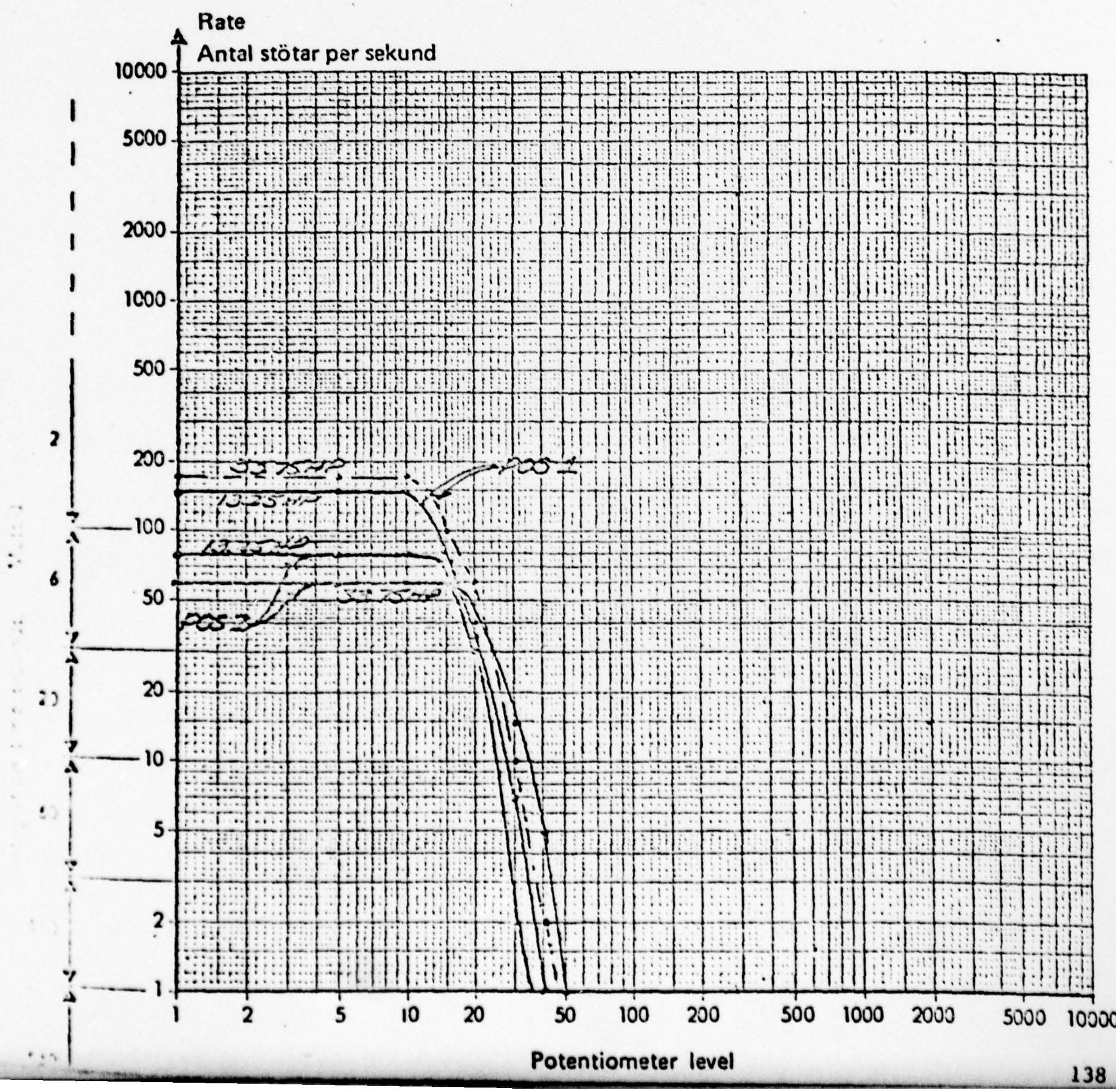
SPEED: 3570 RPM

AMBIENT: 78°F

GEAR BOX TEMP: 160°F at 33.75 HP

153°F at 13.25 HP

ENCLOSURE 21

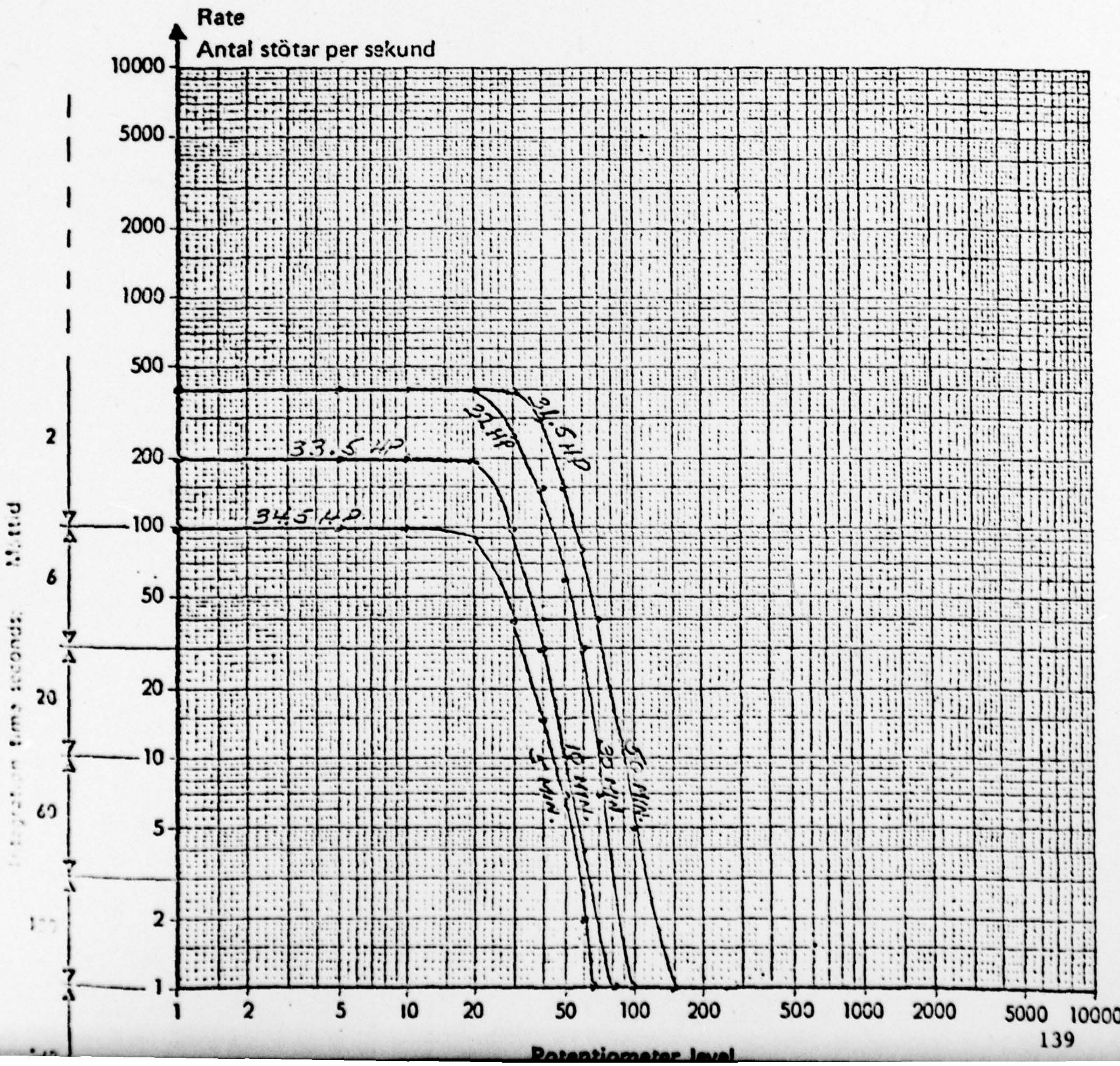


SKF
SHOCK PULSE METER
MEPA 10 A

Rate measurement of shocks per second
Förekomstfrekvens

S/N B13-1561
ARTIFICIALLY DAMAGED GEARS
SPEED: 3540 RPM

ENCLOSURE 22



ENCLOSURE 23

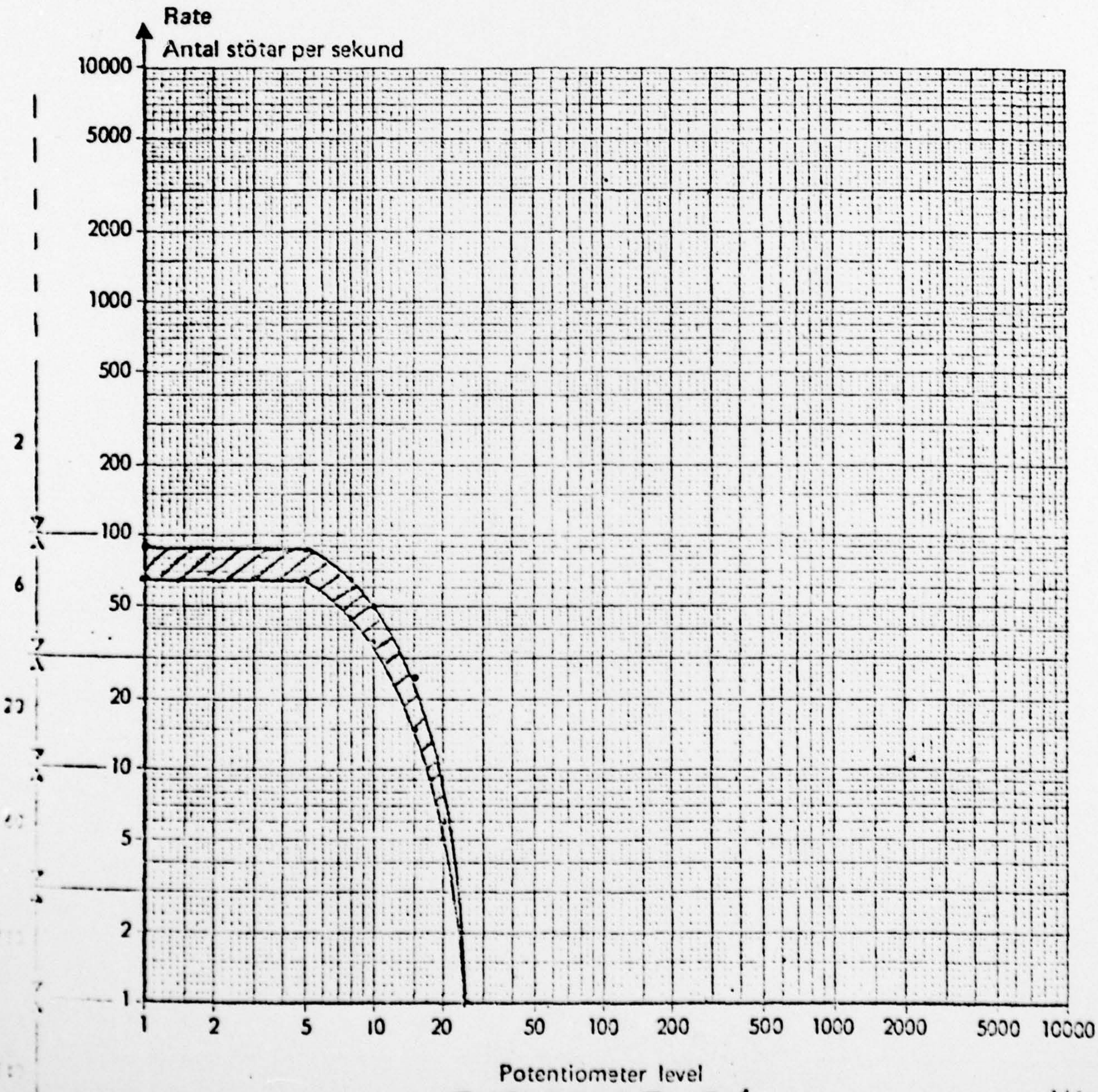
PICTURE TO BE PROVIDED LATER

INPUT GEAR

SHOCK PULSE METER

MEPA 10 A

S/N B13-1561
DAMAGED GEAR
SPEED: 1490 RPM
AMBIENT: 66°F
GEAR BOX TEMP: 102°F
POSITION 2



ENCLOSURE 24

IMPULSE METER

MEPA 10 A

S/N B13-1561

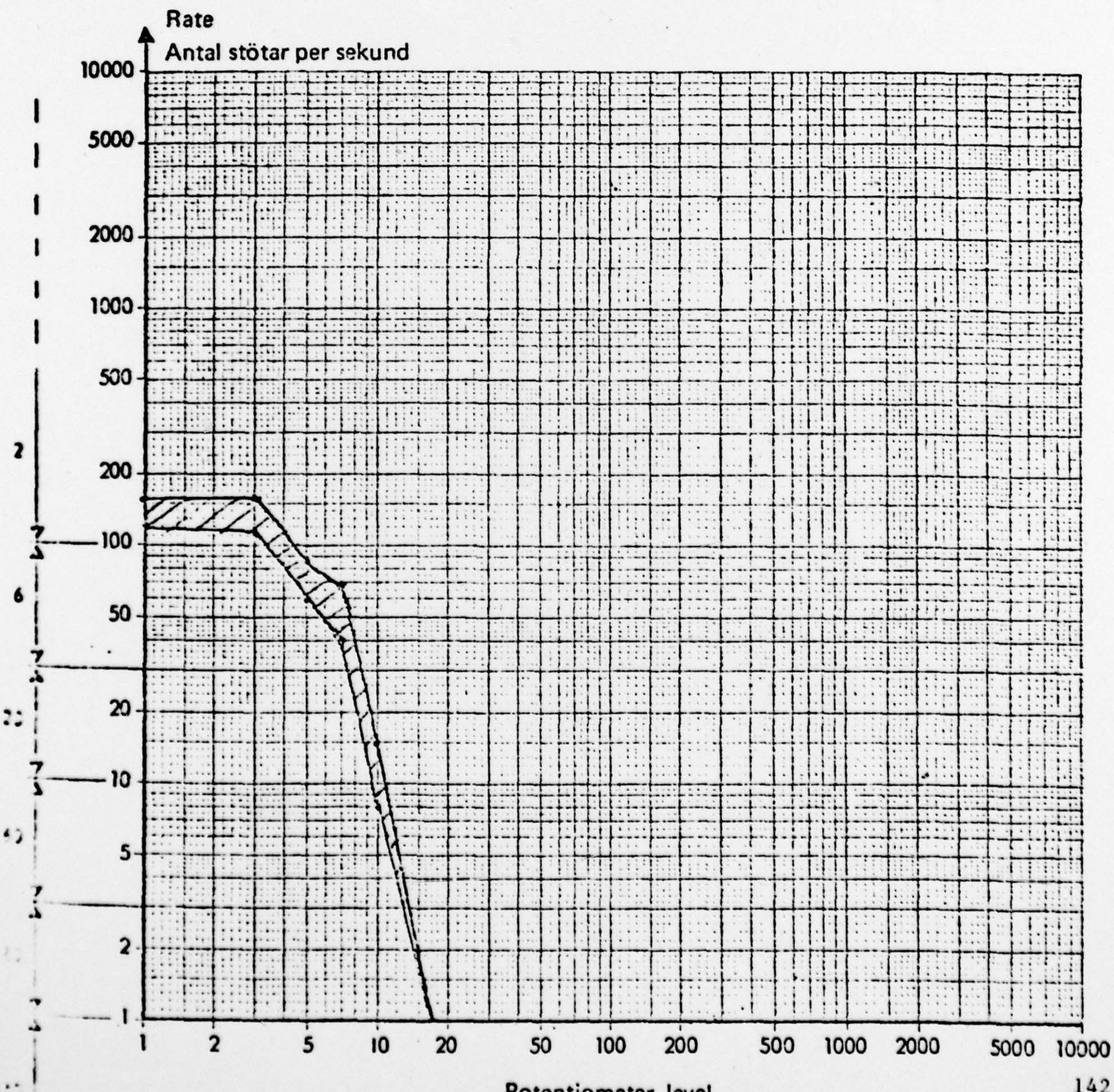
DAMAGED GEARS

SPEED : 1490 RPM

AMBIENT : 68°F

GEAR BOX TEMP: 103°F

POSITION 1



ENCLOSURE 25

SHOCK PULSE METER

WEPA 10 A

Rate measurement of shocks per second

Förekomstfrekvens

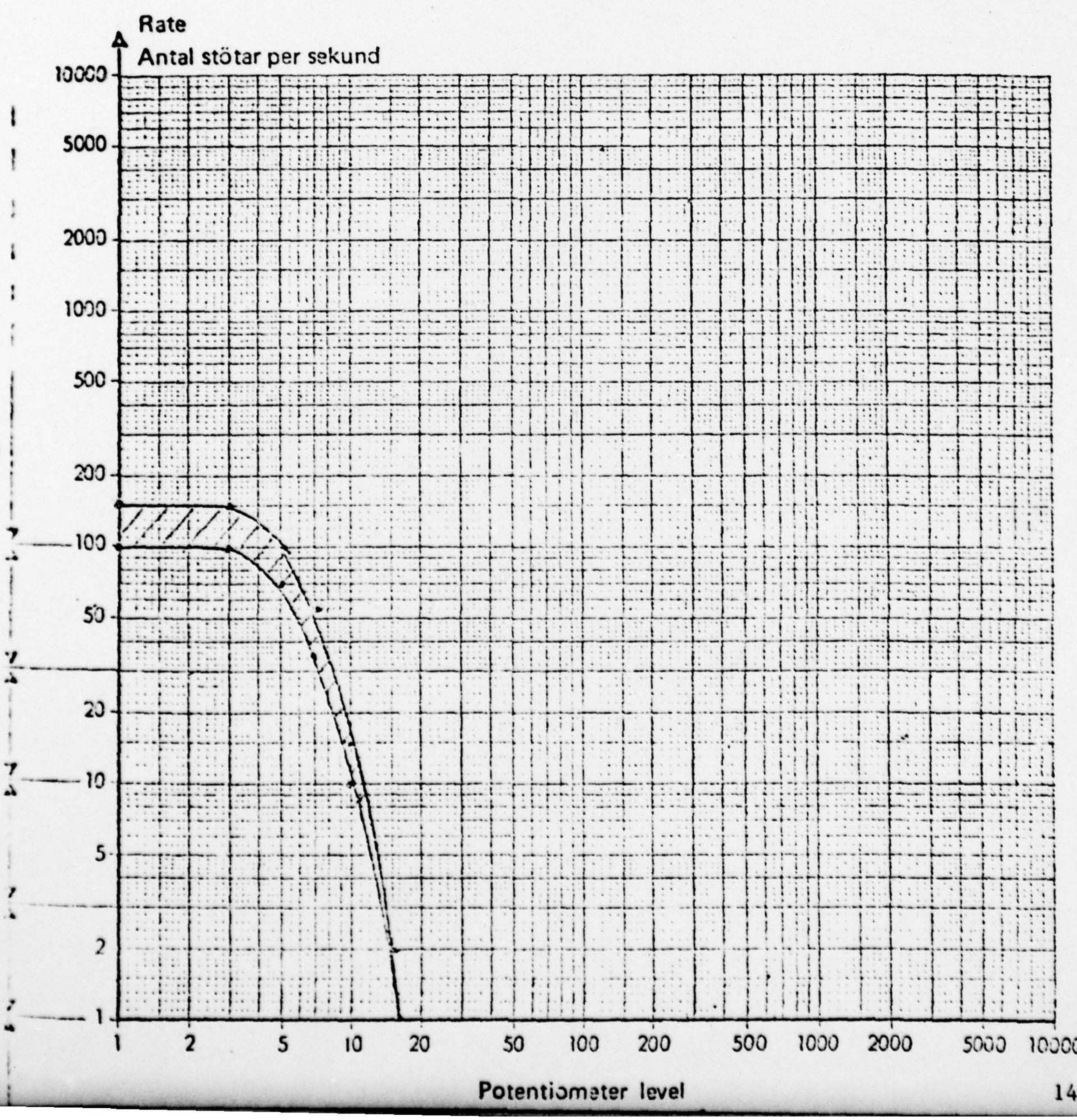
S/N B13-1561

DAMAGED GEARS

SPEED : 1490 RPM

AMBIENT: 68°F

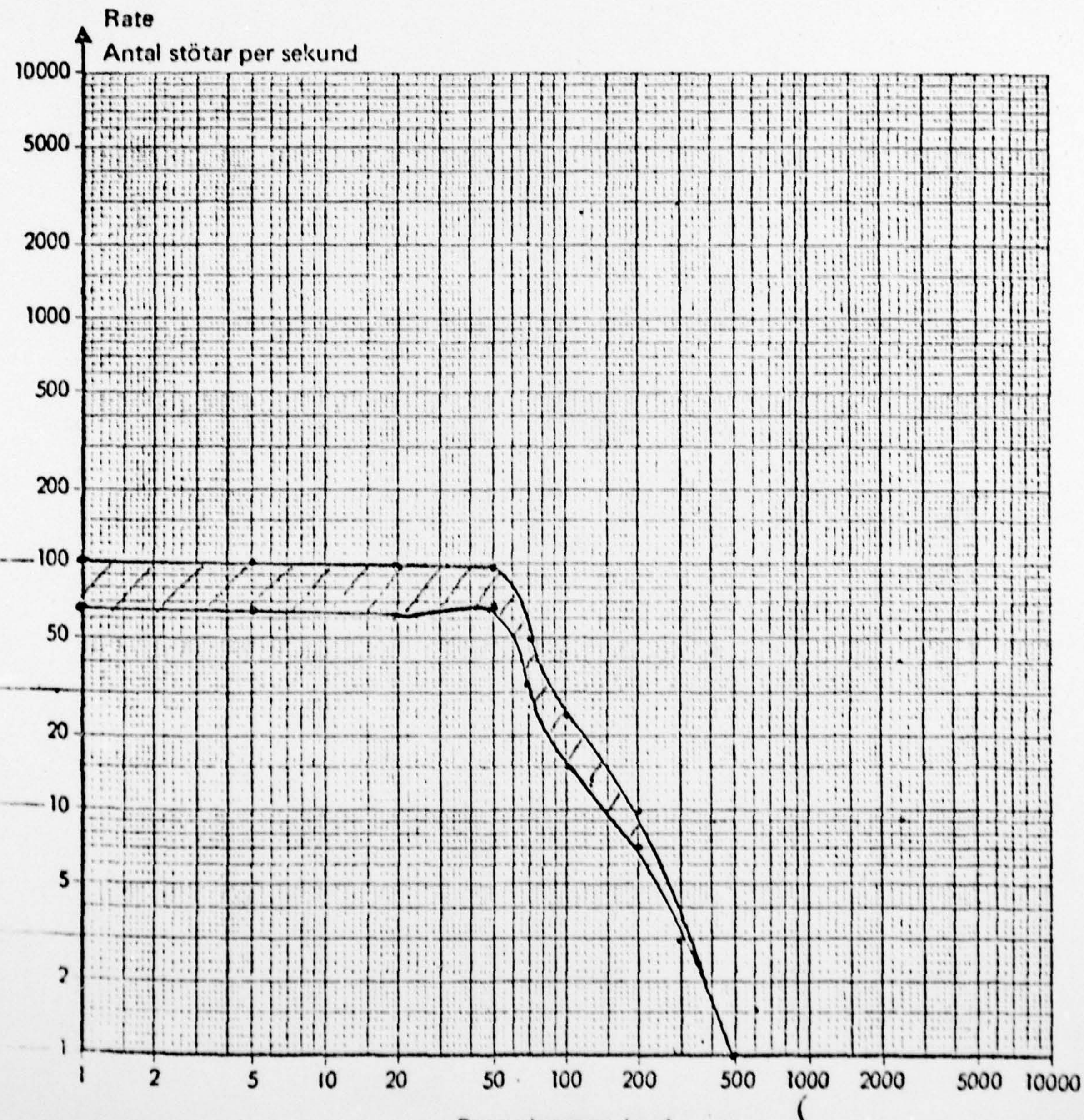
GEAR BOX TEMP: 104°F



...OCK PULSE METER

MEPA 10 A

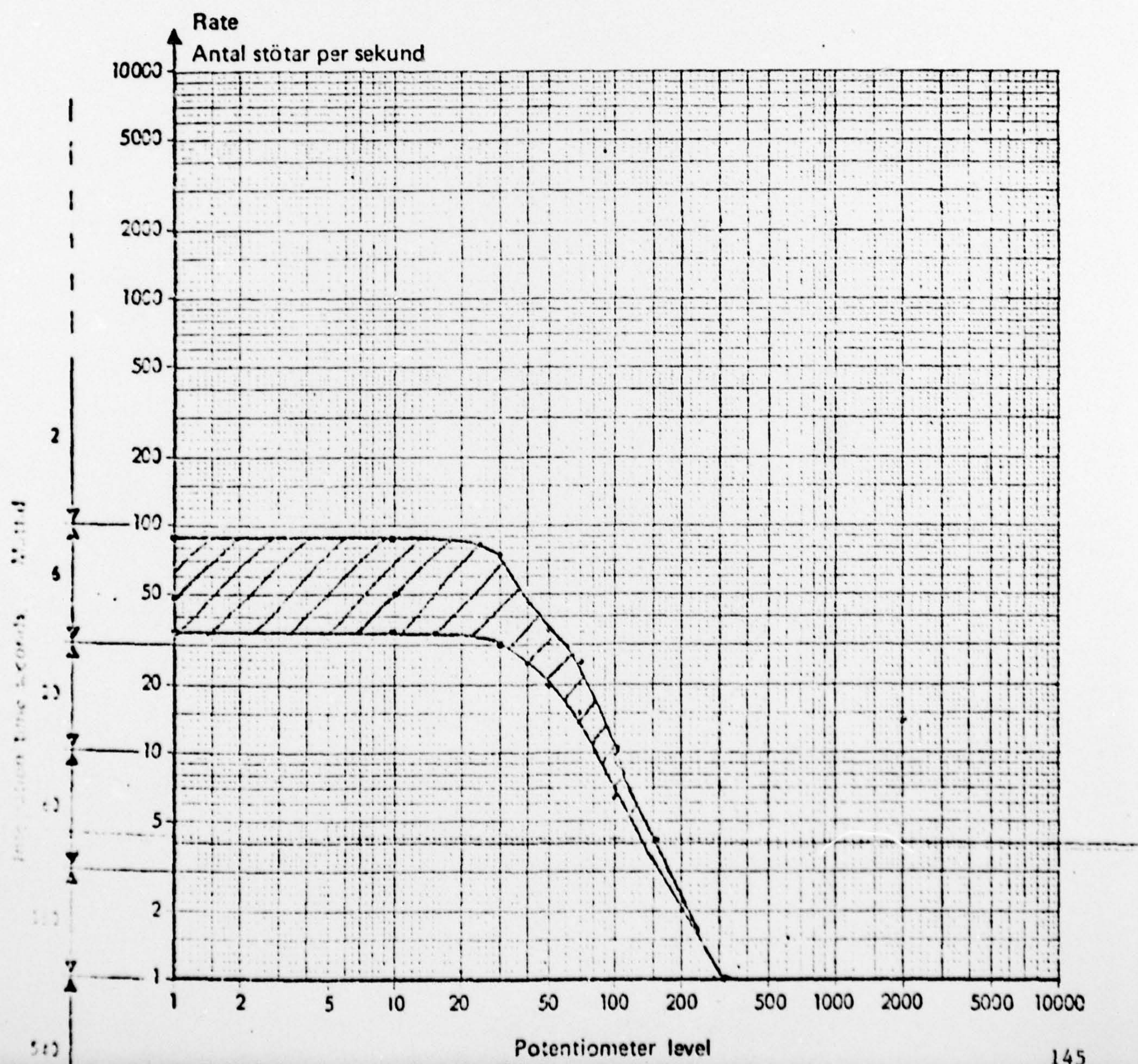
S/N B13-1561
DAMAGED BEARING
SPEED: 1490 RPM
AMBIENT: 70°F
GEAR BOX TEMP: 82°F
POSITION 2



ENCLOSURE 27

SKF SHOCK PULSE METER MEPA 10 A	Rate measurement of shocks per second Förekomstfrekvens	

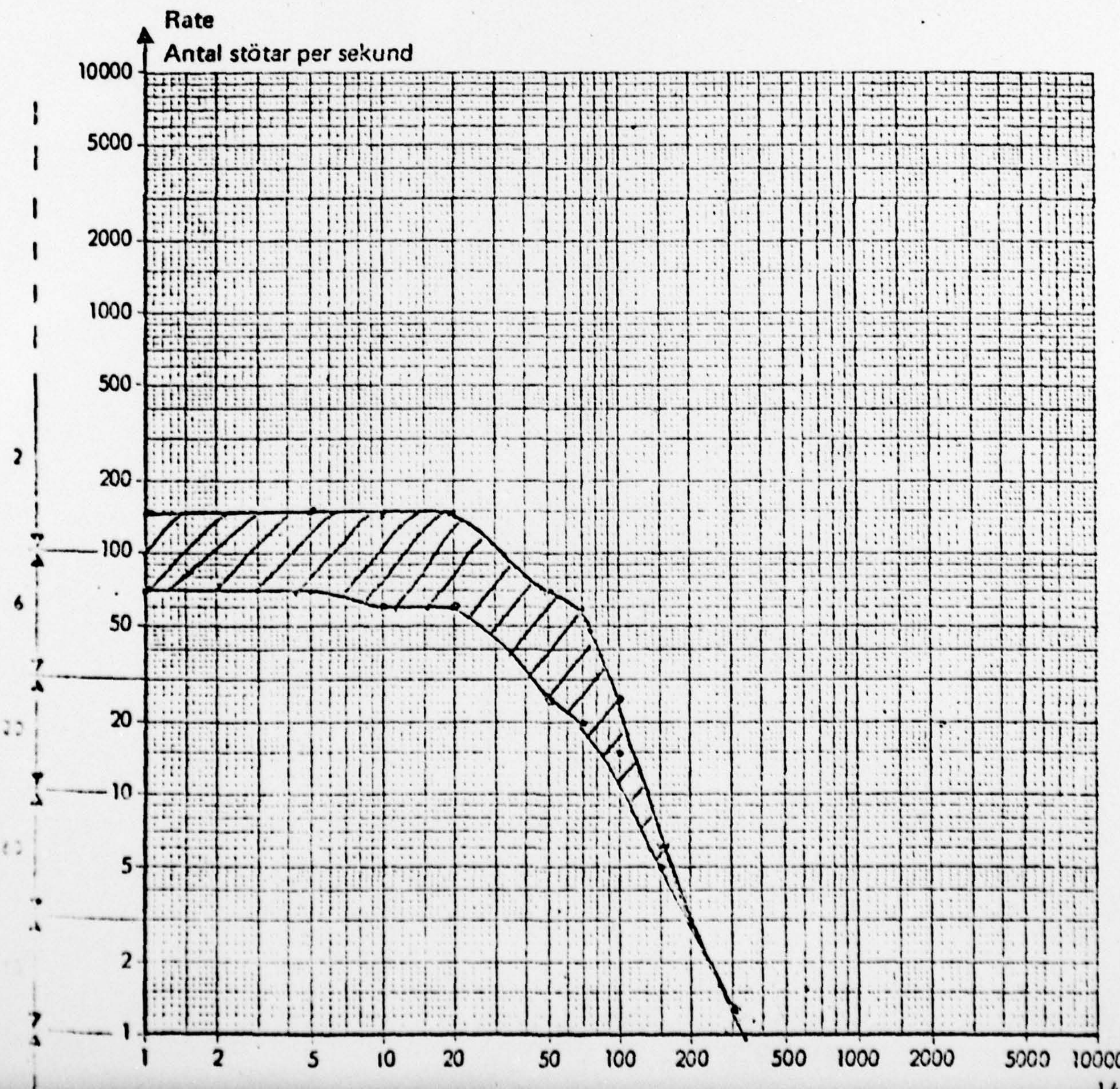
S/N B13-1561
DAMAGED BEARING
SPEED : 1490 RPM
AMBIENT : 71°F
GEAR BOX TEMP: 90°F
POSITION 1



ENCLOSURE 28

SKF SHOCK PULSE METER MEPA-10 A	Rate measurement of shocks per second Förekomstfrekvens	

S/N B13-1561
DAMAGED BEARING
SPEED : 1490RPM
AMBIENT: 71°F
GEAR BOX TEMP: 95°F



ENCLOSURE 30

PICTURE TO BE PROVIDED LATER

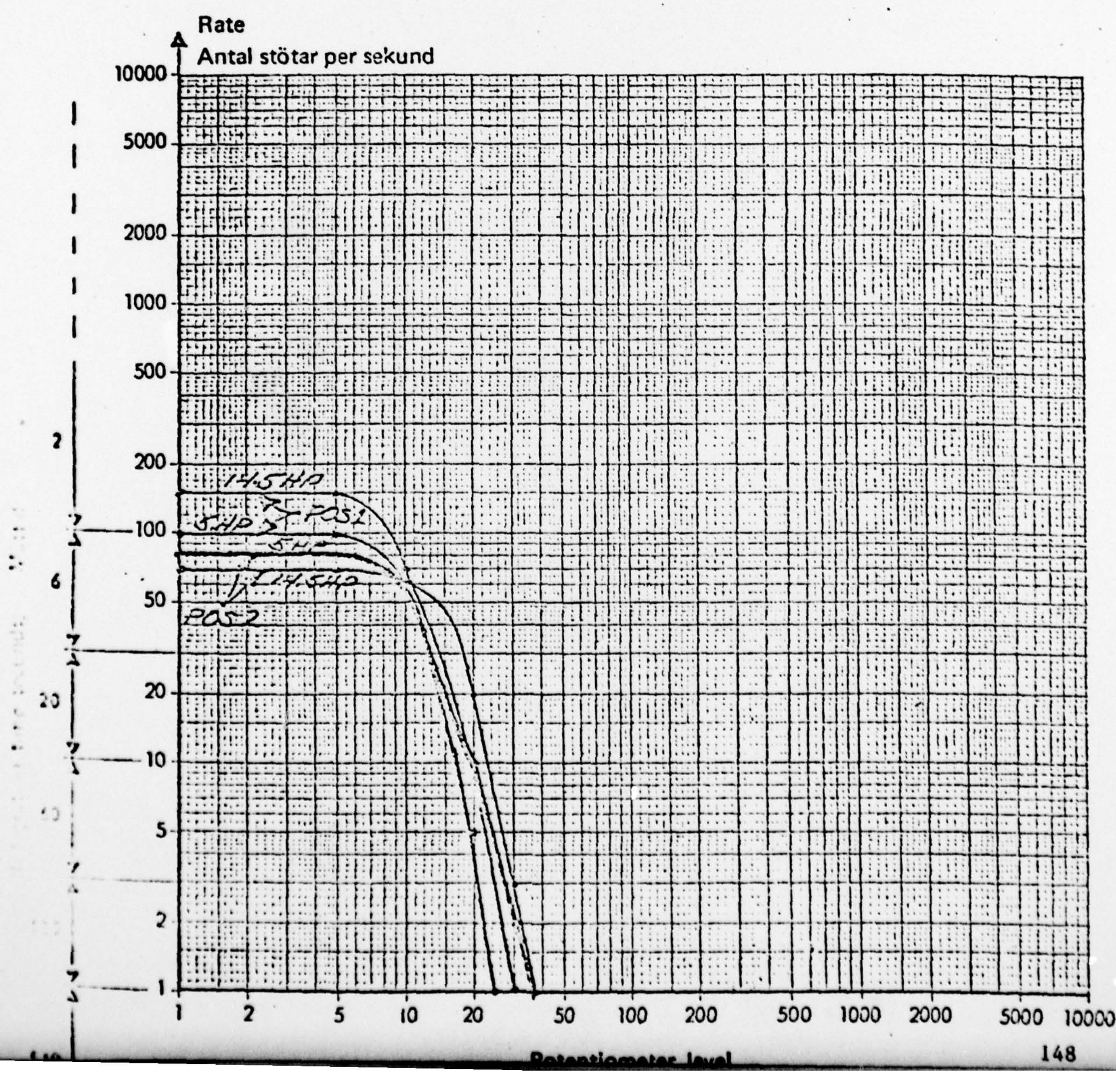
SKF SHOCK PULSE METER
MEPA 10 A

Rate measurement of shocks per second
Förekomstfrekvens

S/N 333-1253
BASELINE DATA

SPEED: 1520 RPM
AMBIENT: 70°F
GEAR BOX TEMP: 98°F at 5 HP
103°F at 14.5 HP

ENCLOSURE 31



SHOCK PULSE METER

MEPA 10 A

Förekomstfrekvens

S/N 333-1255

BASE LINE DATA

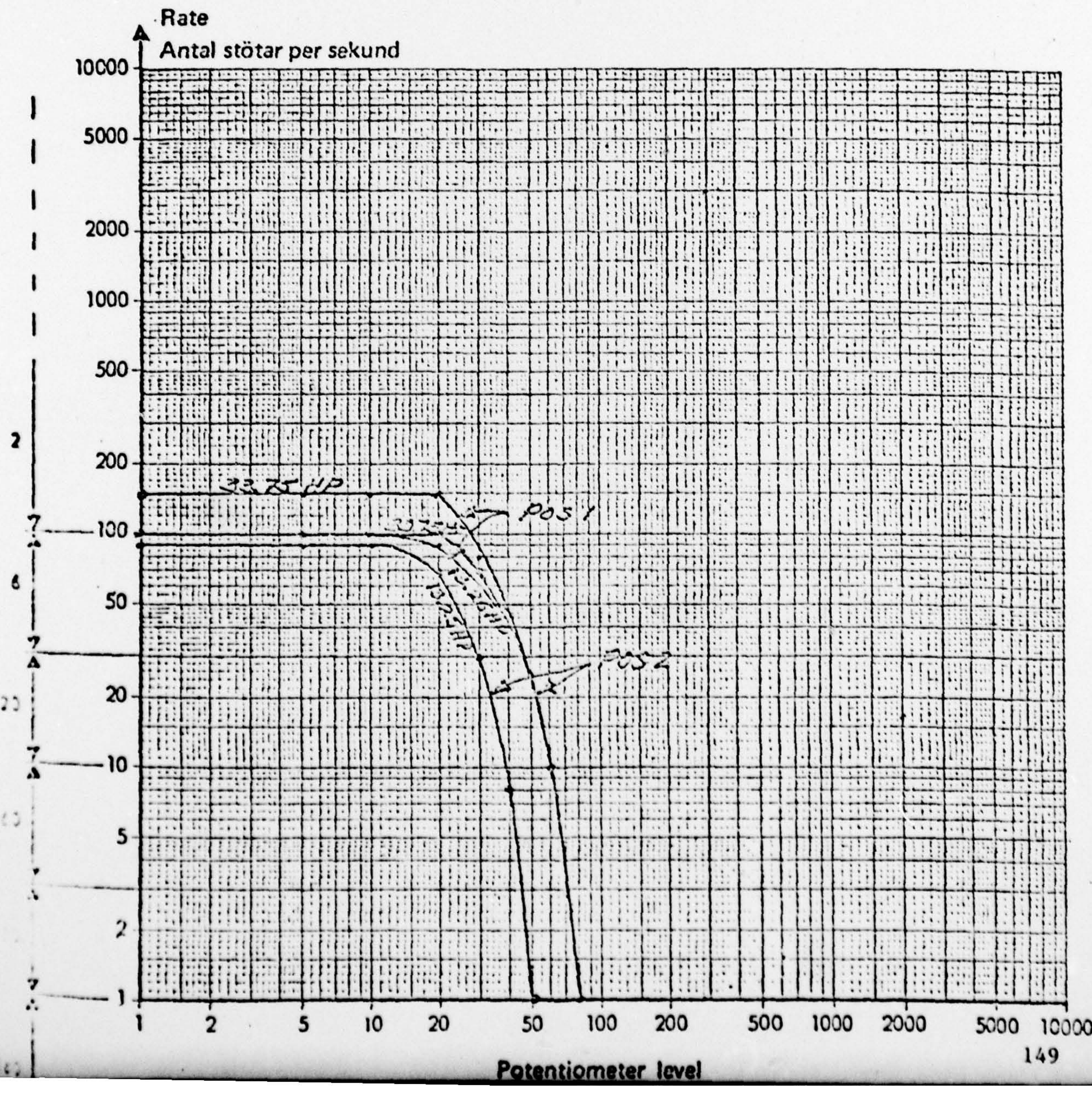
SPEED : 3540 RPM

AMBIENT: 92°F

GEAR BOX TEMP: 173°F at 13.25 HP

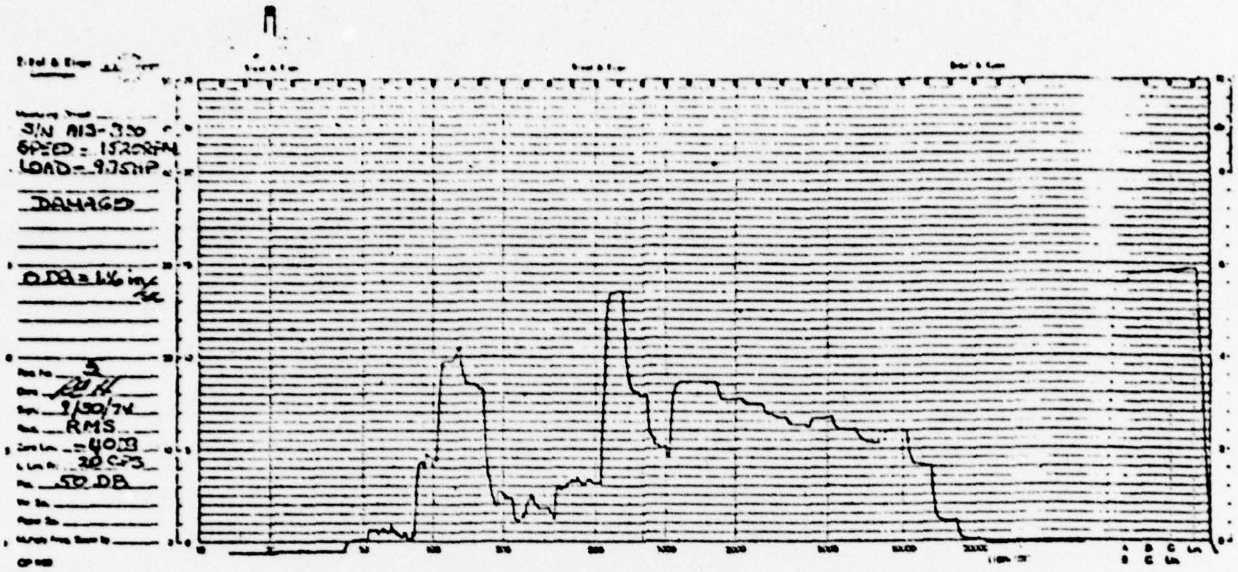
180°F at 33.75 HP

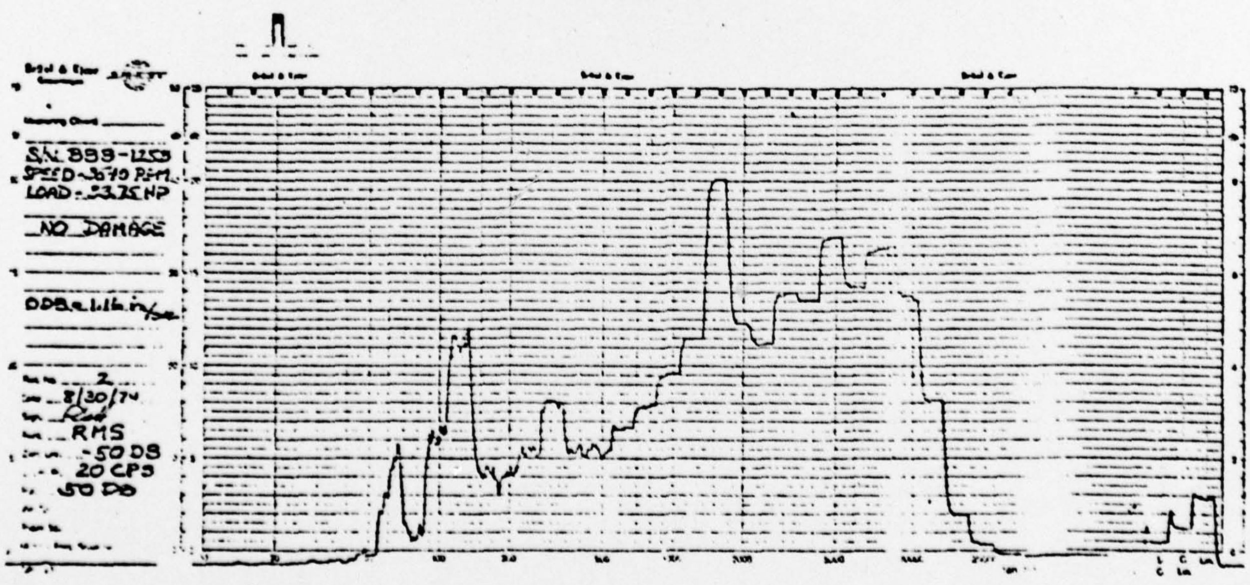
ENCLOSURE 32



GEAR BOX	CONDITION	LOAD (HP)	SPEED (RPM)	LOW BAND 50-300 cps (μ in/sec)	MID BAND 300-1800 cps (μ in/sec)	HIGH BAND 1000-10000 cps (μ in/sec)
S/N A13-830	DAMAGED GEARS	33.75	3580	34k TO 64k	183k	128k
S/N B13-1561	UNDAMAGED	33.75	3540	64k TO 102k	274k	150k
S/N BBB-1253	UNDAMAGED	33.75	3540	60k TO 144k	348k	256k
S/N B13-1561	ARTIFICIAL DAMAGE	33.75	3540	238k	293k	220k
S/N A13-830	DAMAGED GEARS (2nd Set)	33.75	3540	219k	549k	402k
S/N BBB-1253	UNDAMAGED	14.5	1520	40k TO 56k	121k	44k
S/N B13-1561	ARTIFICIAL DAMAGE	14.5	1520	48k	311k	33k
S/N A13-830	DAMAGED GEARS	14.25	1510	220k	220k	37k

ENCLOSURE 33





ENCLOSURE 34 AND 35

RESEARCH LABORATORY SKF INDUSTRIES, INC.

6.0 REFERENCES

1. E. F. Covill, T. C. Mayer, J. A. George; "Preliminary Evaluation of the Shock Pulse Technique to the UH-1 Series Helicopters"; Parks College of Saint Louis University, Cahokia, Illinois; Jan. 1974.

2. T. C. Mayer, E. F. Covill, J. A. George, J. T. Harrington; "Field Evaluation of the Shock Pulse Technique to the UH-1 Series Helicopter, Final Report"; Parks College of Saint Louis University, Cahokia, Illinois; June 1974.

3. J. A. George, T. C. Mayer, E. F. Covill; "Evaluation of the Shock Pulse Technique to the UH-1 Series Helicopter" Paper presented at the 45th. Shock and Vibration Symposium, Dayton, Ohio; Oct. 1974.